TECHNICAL REPORT

NATICK/TR-82/039

INTENSIVE AGRICULTURE UNIT (HYDROPONICS)

BY

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AND

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NUTRIENT SOLUTION	NUTRIENT ANALYSIS	SUPPORT MODULE
ENVIRONMENTAL CONTROL	NUTRIENT FILM TECHNIQUE	HYDROCULTURE
GROW LAMPS	GROW BLOCKS	NUTRICULTURE

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A field test of Hydroponic Units was conducted at the US Naval Facility, Argentia, Newfoundland under United States Navy Requirement USN 5–4, Intensive Agriculture Unit. Hydroponics is the growing of plants without soil using a nutrient solution. The units were environmentally controlled to temperature, humidity, and lighting wavelength and intensity. Salad portions (leaf lettuce, cukes, and tomatoes) were harvested daily for 200 personnel, two meals per day over a period of 18 months. Two naval personnel without agricultural background

20. ABSTRACT (cont'd)

were trained and successfully operated the facility using standard operating procedures provided by the manufacturer. Operating costs were developed for the total operation to compare to estimates and costs derived by NLABS and the University of Connecticut.

PREFACE

Hydroponic agriculture, also called hydroculture, is the growing of plants without soil using a nutrient solution. It offers the military and others the opportunity to provide needed vegetables in an environment not conducive to growing because of climate, poor or diseased soil, and lack of or an unpredictable water source.

This report covers a field test of hydroponic units in a frigid environment that was carried out by the Navy with the guidance of NLABS under a United States Navy requirement (USN 5–4) for an Intensive Agriculture Unit (AH99BB068) and NLABS project number 1G263747D610104018. In the Appendices is an analysis by Dr. Walter E. Ballinger, LTC, QM, USAR Mobilization Designee and Professor of Horticultural Science, North Carolina State University, Raleigh, NC 27607.

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INTENSIVE AGRICULTURE UNIT

INTRODUCTION

Some authorities date the origin of the hydroponic method back to 1699 when plants were experimentally grown in water to determine the minerals necessary for growth. On a commercial basis, however, hydroponic agriculture is quite new especially when used in combination with a controlled environment.

During World War II, hydroponic agriculture received some attention in the United States because of the vast global commitments of the military. Early in 1945, an experimental system was established in the Caroline Islands. Encouraging results caused additional ones to be installed as the military "island-hopped" across the Pacific.

During the early occupation of Japan, an 80-acre installation supplied fresh vegetables to US forces in Korea and eventually to all the troops in Japan. In most of these cases, the environment was not controlled, since natural sunlight and good growing temperatures were available year-round. After World War II, with a reduced Armed Forces and a greatly reduced need of shipping arms and ammunition, it became more economically feasible to ship fresh vegetables from the US or to buy them locally. Hydroponics in most cases was abandoned since air and sea shipping was relatively cheap and readily available.

Because of its vast global commitment, the United States stations military units in remote areas or on ships that are at sea for long periods of time without resupply. This results in transportation costs that have increased several times in the past decade. Consequently it became apparent to the Services, especially the Navy (see Appendix A), that hydroponics might be a way to supply these remote units around the world. In 1976, a Military Service Requirement, USN 5–4, was written and the Food Engineering Laboratory (FEL), Natick Laboratories, submitted a proposal for an Intensive Agriculture Unit (IAU) test plan.

On 22 July 1976, at a meeting convened at these laboratories by the Deputy Technical Director for Food Service Programs (DTD/FSSP), the following course of action was directed:

1. That FEL would gather information for a final IAU Test Plan and for awarding a contract to carry out the test.

2. That the Operations Research and Systems Analysis Office (ORSAO) would make an in-house cost benefit analysis with the assistance of FEL personnel.

Subsequently, ORSAO's analysis indicated that the IAU system was not cost-effective at that time. However, an analysis by Dr. Walter E. Ballinger, LTC, QM, USAR, of North Carolina State University, a Mobilization Designee on active duty at NLABS, (see Appendix B) concluded: "From a cost, quality, availability, and energy consumption standpoint, production of leaf lettuce in an IAU at the US Naval Facility at Argentia, Newfoundland appears to be highly feasible." Therefore, FEL recommended that a field test be conducted in order to obtain operational data relative to the suitability of the IAU for military feeding systems as well as to the actual cost-effectiveness. An unsolicited proposal from General Electric for a transportable facility was evaluated by FEL and was accepted. The contract was awarded to General Electric; with installation planned for the Naval Facility at Argentia, Newfoundland.

DESCRIPTION OF EQUIPMENT

The hydroponics facility provided by General Electric Co. (called by the trademark name "Geniponics") consists of one support (service) module and three grow modules, as depicted in Figure 1 (from unsolicited GE proposal "Geniponics Transportable System" (an Intensive Agriculture Unit) dated February 1977).

Support Module

The support module (see Figure 2) is 12 feet by 36 feet by 16 feet 6 inches mounted on skids. It provides shelter for all support equipment such as utilities and air conditioning servicing the grow modules. It has an air-lock entrance and access to the grow modules.

Grow Module

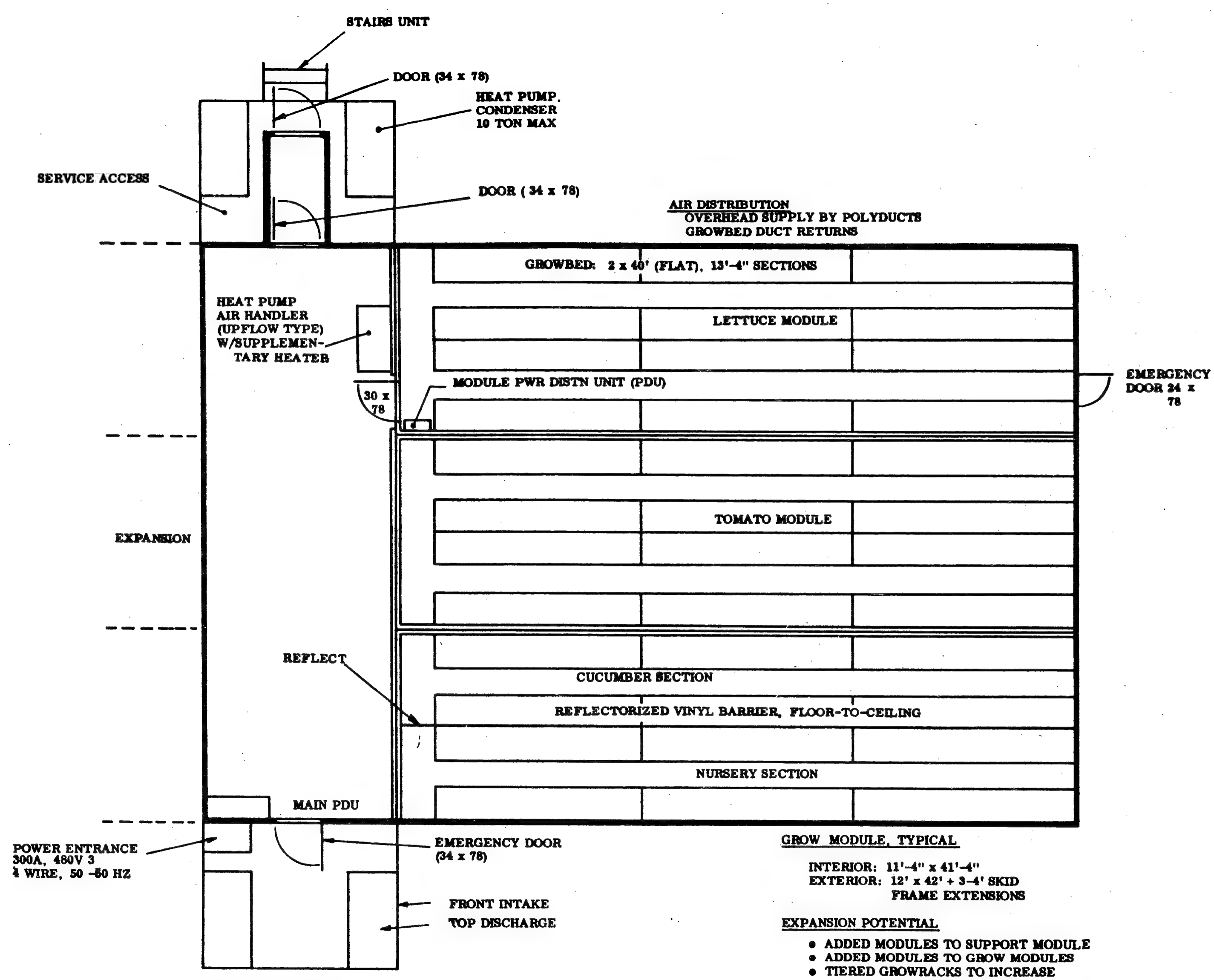
Each grow module (see Figure 2) is 12 feet by 42 feet by 13 feet 6 inches mounted on skids. Each is insulated to provide operation in a climatic temperature range of −40°F to +120°F and contains Lucalox high-intensity discharge lamps for maximum growth in the absence of natural sunlight (see Figure 3).

Climate Control

The grow modules (see Figure 4 and 5) are temperature and humidity controlled. Humidity is added to each module by using fog nozzles that utilize water collected from the air-conditioner coils. They also can provide carbon dioxide enriched atmosphere as required by the vegetable being grown. The CO_2 level can be monitored and controlled between 300 and 2500 parts per million (PPM). Carbon dioxide can be supplied from a liquid CO_2 tank or a compressed CO_2 gas cylinder.

Growing Method

The growing method utilized is the Nutrient Film Technique. It involves continually recirculating a shallow stream of water containing all the nutrients required for plant growth past the roots of the plant (see Figure 6). Crops are planted in cubes of growing media and then placed at prescribed intervals into a plastic grow tube through which the nutrient solution flow. This solution enters the grow tube from a main supply pipe, flows down the grow tube by gravity to a catchment tube at the other end and is then circulated back to the nutrient reservoir in order to be recycled to the grow tube. The liquid depth is maintained so that a thick root mat develops above the film (waterline). This procedure insures that all the roots are moist and that the upper surface of the root mat is in air and exposed to an adequate supply of oxygen even at the end of the grow tube. The concentrations of the nutrient are monitored by measuring electrical conductivity and pH and additional nutrient concentrates are automatically injected into the system when needed.



GROW MODULE, TYPICAL

INTERIOR: 11'-4" x 41'-4"
EXTERIOR: 12' x 42' + 3-4' SKID FRAME EXTENSIONS

EXPANSION POTENTIAL

- ADDED MODULES TO SUPPORT MODULE
- ADDED MODULES TO GROW MODULES
- TIERED GROWRACKS TO INCREASE EXISTING, MODULE UTILIZATION

SUPPORT MODULE

INTERIOR: 11'-4" x 35'-4"
EXTERIOR: 12' x 54' + 3-4' SKID FRAME EXTENSIONS (EACH EQUIPMENT DECK 9' x 12')

Figure 1. Facility Layout

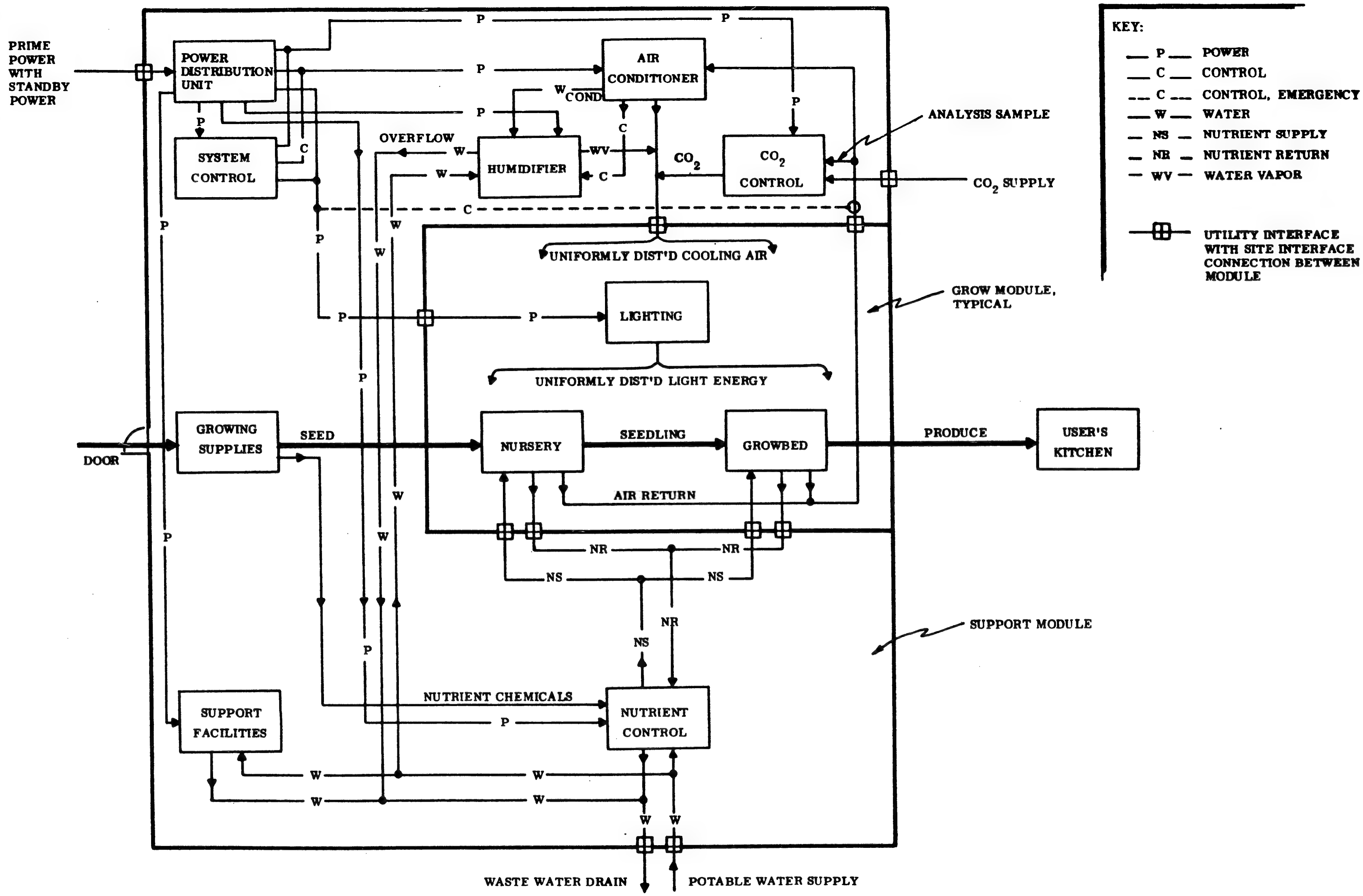


Figure 2. System Flow Diagram

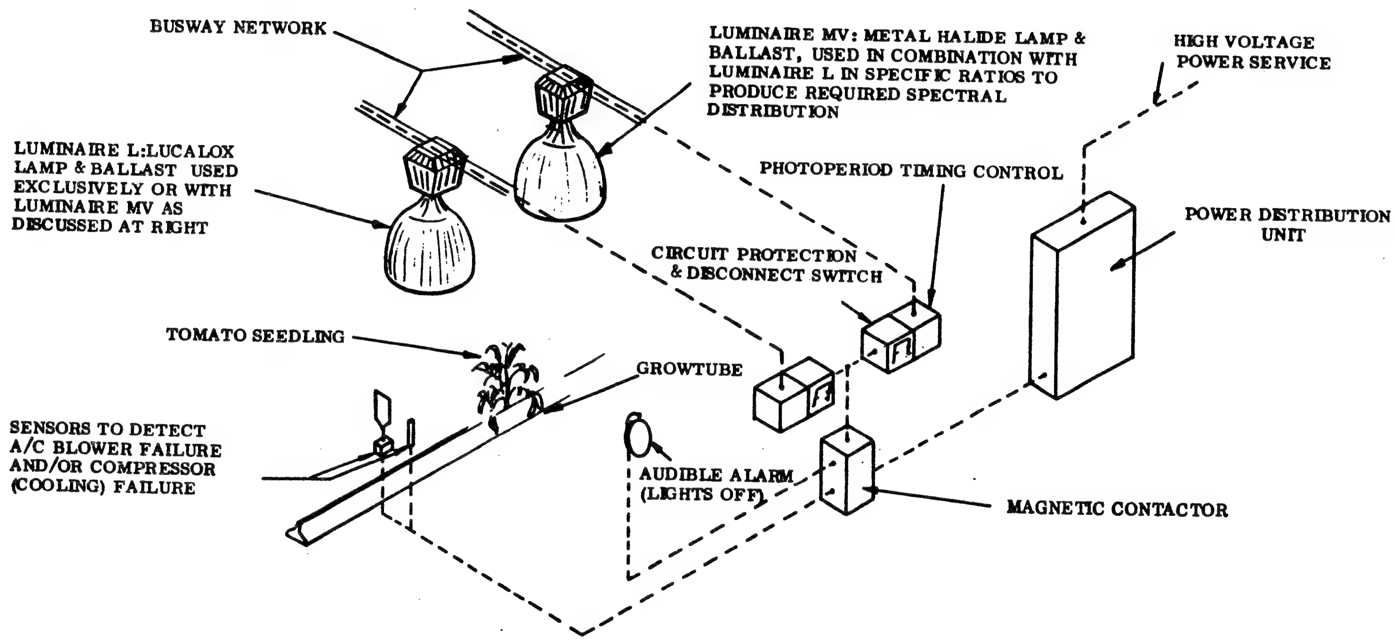


Figure 3. Lighting Subsystem

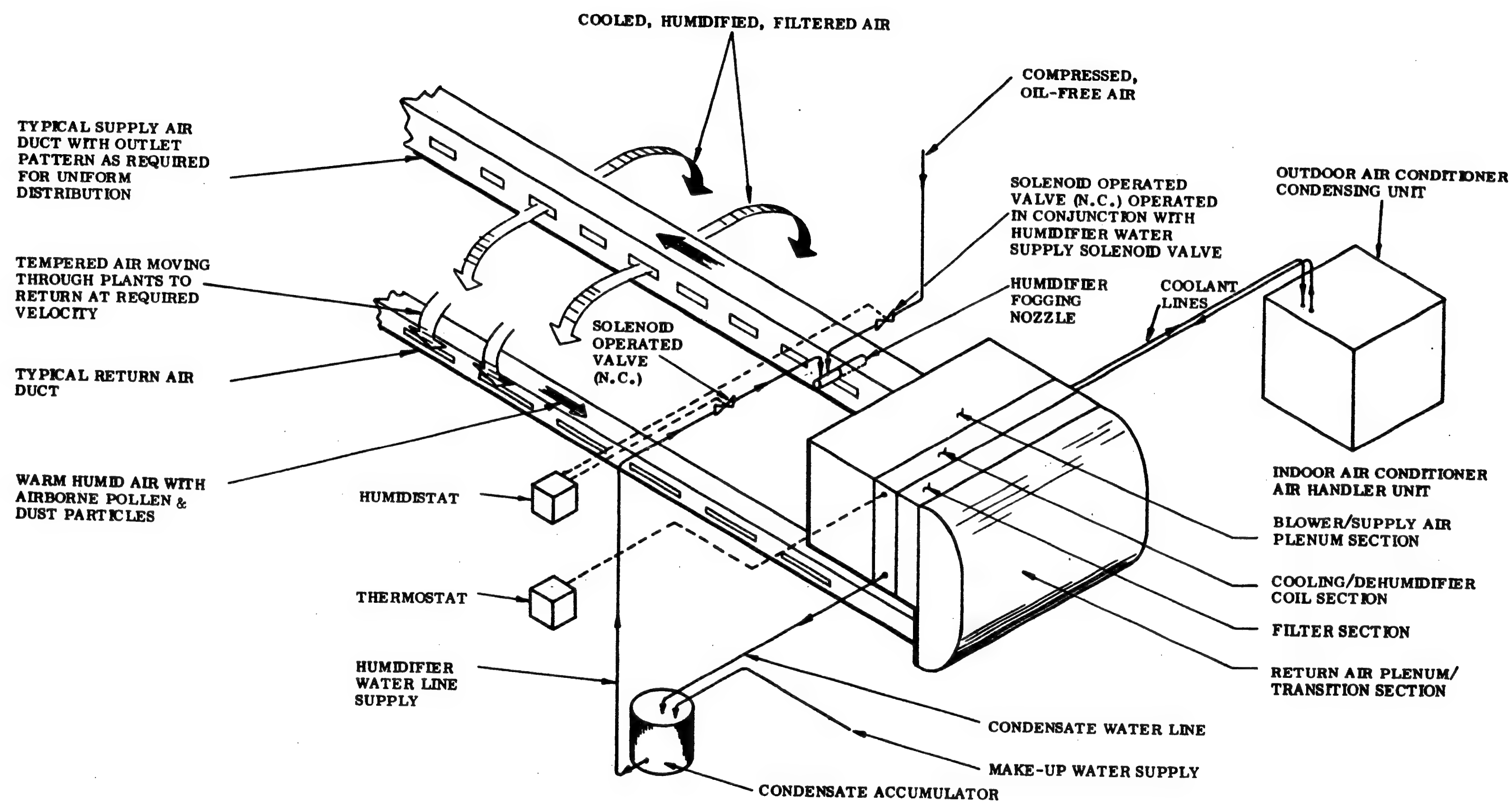


Figure 4. Air Conditioning Subsystem

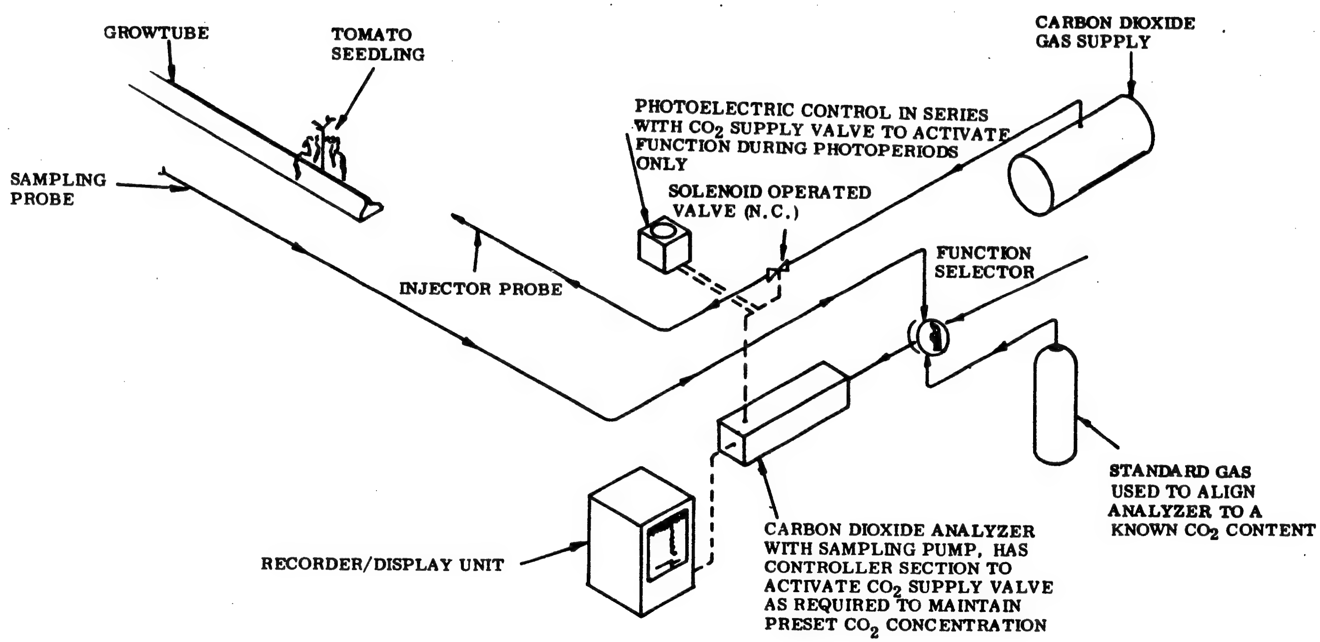


Figure 5. Carbon Dioxide Subsystem

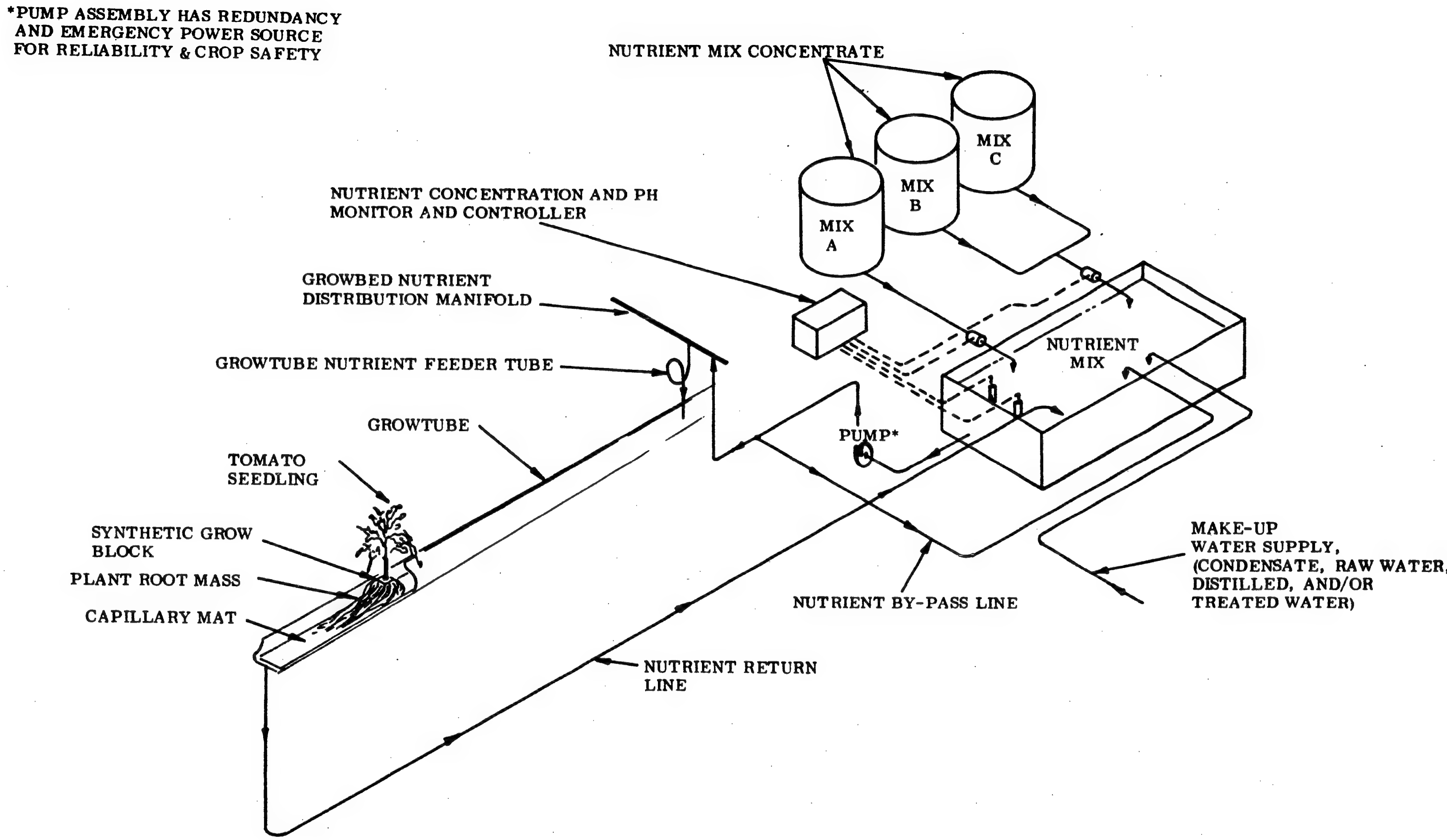


Figure 6. Nutrient Subsystem

TYPICAL OPERATING PROCEDURES

Lettuce

The basic operation for growing lettuce consists of planting seeds, transplanting seedlings, pruning, and harvesting. Lettuce seeds are started in grow blocks and placed in the seed area for 14 days. The seedlings are culled and the selected plants (in grow blocks) are placed in the grow tubes on 5-inch spacings. The system automatically feeds the required nutrients, and 21 days later the plants are harvested. The plants are cut at the rootline and no cleaning is required. The grow blocks are removed from the tube and recycled to the seed area. By repeating the five-week cycle/process, a fresh crop can be planted and another harvested each day. Other crops can be handled similarly by using slightly different techniques and time frames.

Tomatoes

The procedure for tomatoes is different than for lettuce. After one week the first seedlings are transported to a nursery where the best are spread out for two weeks initial growth. These larger plants are then transplanted to another nursery for final growth and harvesting. See Figures 7, 8, and 9 for a typical operation.

WEEK #				
37				PLACE IN BED A
36			FINAL NURSERY	
35		2ND GROWTH STAGE		PLACE IN BED H
34	1ST GROWTH STAGE		FINAL NURSERY	
33	SEED	2ND GROWTH STAGE		PLACE IN BED G
32	1ST GROWTH STAGE		FINAL NURSERY	
31	SEED	2ND GROWTH STAGE		PLACE IN BED F
30	1ST GROWTH STAGE		FINAL NURSERY	
29	SEED	2ND GROWTH STAGE		PLACE IN BED E
28	1ST GROWTH STAGE		FINAL NURSERY	
27	SEED	2ND GROWTH STAGE		PLACE IN BED D
26	1ST GROWTH STAGE		FINAL NURSERY	
25	SEED	2ND GROWTH STAGE		PLACE IN BED C
24	1ST GROWTH STAGE		FINAL NURSERY	
23	SEED	2ND GROWTH STAGE		PLACE IN BED B
22	1ST GROWTH STAGE		FINAL NURSERY	
21	SEED	2ND GROWTH STAGE		PLACE IN BED A
20	1ST GROWTH STAGE		FINAL NURSERY	
19	SEED	2ND GROWTH STAGE		PLACE IN BED H
18	1ST GROWTH STAGE		FINAL NURSERY	
17	SEED	2ND GROWTH STAGE		PLACE IN BED G
16	1ST GROWTH STAGE		FINAL NURSERY	
15	SEED	2ND GROWTH STAGE		PLACE IN BED F
14	1ST GROWTH STAGE		FINAL NURSERY	
13	SEED	2ND GROWTH STAGE		PLACE IN BED E
12	1ST GROWTH STAGE		FINAL NURSERY	
11	SEED	2ND GROWTH STAGE		PLACE IN BED D
10	1ST GROWTH STAGE		FINAL NURSERY	
9	SEED	2ND GROWTH STAGE		PLACE IN BED C
8	1ST GROWTH STAGE		FINAL NURSERY	
7	SEED	2ND GROWTH STAGE		PLACE IN BED B
6	1ST GROWTH STAGE		FINAL NURSERY	
5	SEED	2ND GROWTH STAGE		PLACE IN BED A
4	1ST GROWTH STAGE		FINAL NURSERY	
3	SEED	2ND GROWTH STAGE		
2	1ST GROWTH STAGE			
1	SEED			
0				
	AREA 1 - NURSERY 2 X 2 SPACING 30 PLANTS = 1 ft^2	AREA 2 - NURSERY 4 X 4 SPACING 30 PLANTS = 4 ft^2	AREA 3 - NURSERY 6 X 6 SPACING 30 PLANTS = 8 ft^2	

Figure 7. Seeding and Planting Cycle for Tomatoes

TOMATOES

8 - 10 FOOT BEDS   PLANTS TO CARRY 8 CLUSTERS OF FRUIT, EACH CLUSTER HAVING AN AVERAGE OF 6 FRUIT.

YIELD - AFTER START-UP 4 BEDS WOULD BE HARVESTED AT ALL TIMES YIELDING A TOTAL OF 115 POUNDS OF TOMATOES PER WEEK.

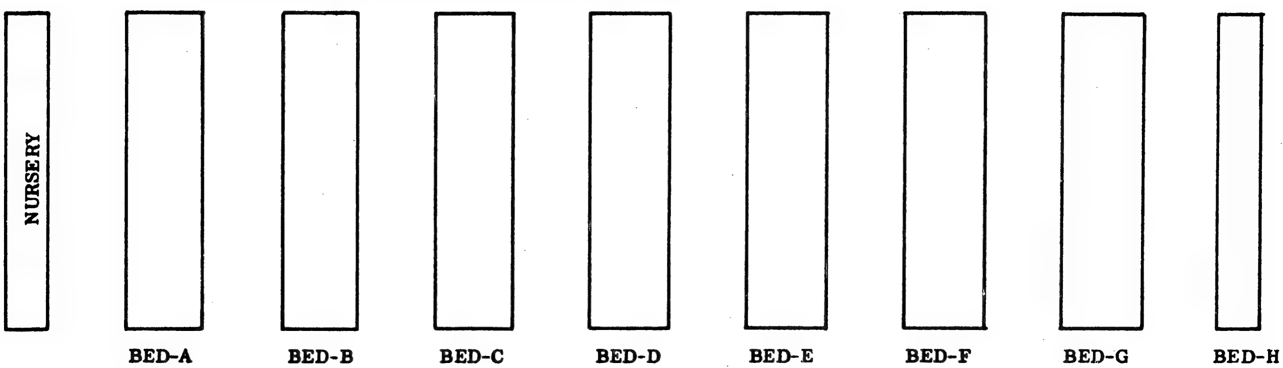


Figure 8. Growing Cycle Time Sequence Example for Tomatoes

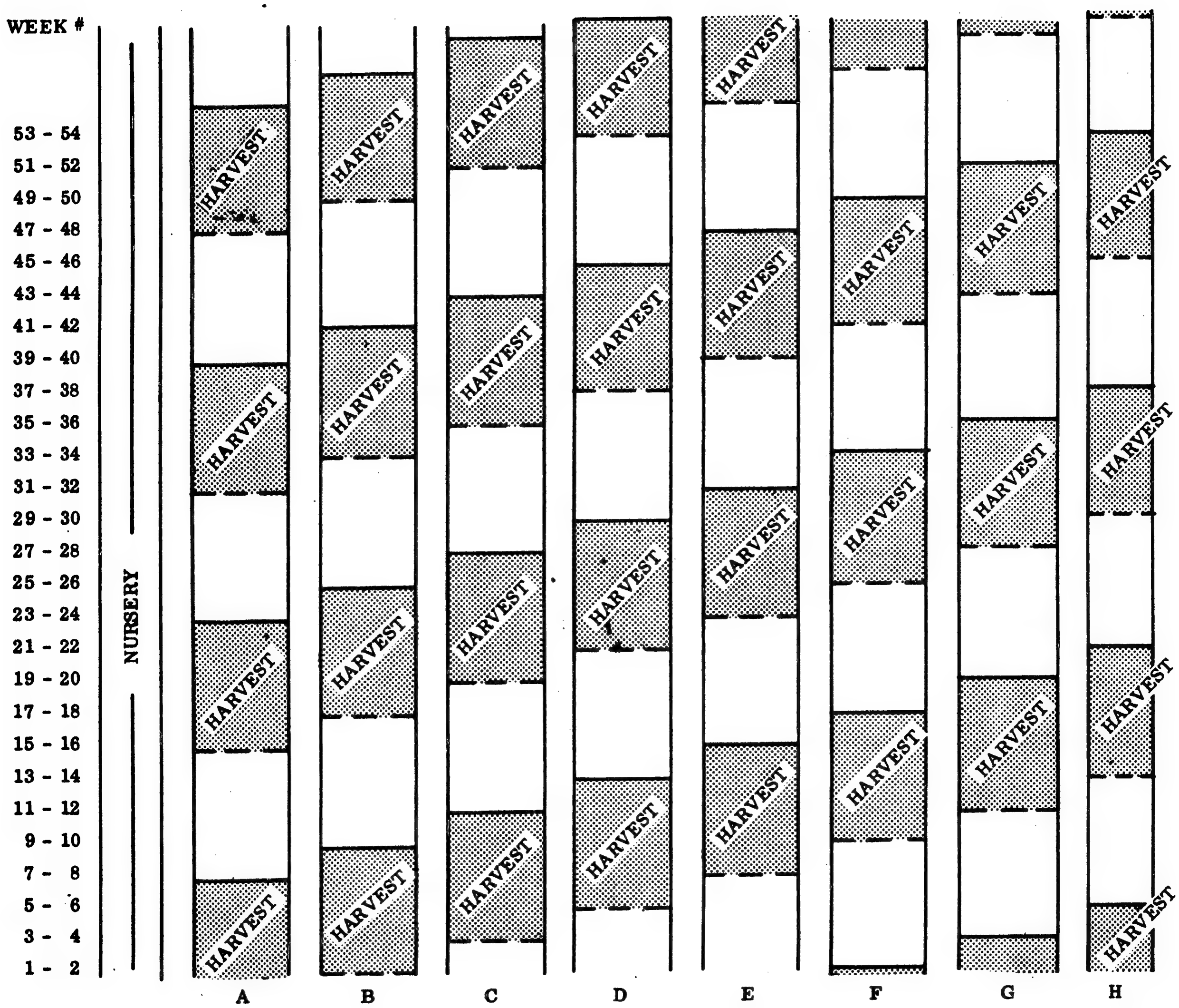


Figure 9. Harvest Cycle Example for Tomatoes

RESULTS AND DISCUSSION

General Electric Co. delivered the unit to the Naval Facility, Argentia, Newfoundland on 14 January 1978. The unit was assembled, put into operation, and first plantings were begun by 1 October 1978. During the first three months, General Electric personnel trained naval personnel in the operation of both the grow and service modules. Planting, growing, and harvesting were done according to Standard Operating Procedures provided by General Electric. The growing operation required only one, and sometimes two, naval personnel with no technical background to successfully produce in excess of 200 salad portions per day for an enlisted personnel dining facility.

1. **Yields.** The monthly yields in pounds are listed below in Table 1. Variations in quantities are a consequence of variation in the experiments, trial methods being used, and equipment failure.

Table 1. Monthly Vegetable Yields, in Pounds

Month	Cucumbers	Tomatoes	Lettuce
October 1978	483	5	70
November 1978	563	316	402
December 1978	641	370	353
January 1979	782	332	306
February 1979	464	207	238
March 1979	542	338	441
April 1979	535	167	551
May 1979	337	200	704
June 1979	120	283	540
July 1979	257	215	452
August 1979	417	176	348
September 1979	188	152	220
October 1979	200	149	64
November 1979	241	332	459
December 1979	0	186	252

Table 1. **Monthly Vegetable Yields, in Pounds (cont'd)**

Month	Cucumbers	Tomatoes	Lettuce	Total
January 1980	51	91	166	
February 1980	156	156	0	
March 1980	256	230	144	
April 1980 (1–21)	170	77	212	
Monthly Averages Nov 78 – Oct 79	420	216	385	1021

For future installation of such units, consideration should be given to expanding the tomato production and decrease the cucumbers, which proved to be easy to produce. Experiments in which cucumbers and tomatoes were grown in the same grow unit proved successful. The average yields during normal operations will provide in excess of the 200 salad portions per day as specified.

2. **Costs of Operation.** The following costs of operation for FY79 and FY80 show a difference in maintenance and lamps because these were one-time items required during the "debugging" operation. The difference in expenditure for supplies was due to a full year's purchase of materials in late FY79 that lasted throughout FY80. FY80 costs were from 1 October to 1 April 1980 (six months).

Table 2. Operational Costs

Item	FY79 (12 months)	FY80 (6 months)
Electricity	$ 7,102	$ 3,051
CO_2	1,550	1,563
Maintenance	1,545	180
Telephone	482	155
Supplies	1,525	360
Lamps	1,141	0
Miscellaneous	202	0
Totals $18,855 (18 months)	$13,546 (12 months)	$ 5,309 (6 months)

For a total of 18 months, during the fiscal years of 1979 and 1980, the average monthly yield of all vegetables was 1021 pounds. Over the same period, their average monthly cost of production was $1,050 giving an overall average cost of $1.03 per pound of produce. This figure does not include armortizing the equipment.

3. **Air-Conditioning System (see Figure 4).** Once the Honeywell thermostats were shielded from the intense heat of the module's light, the temperatures were well controlled. For example, before covering the thermostats the control read 90°F, while the actual module temperature was 78°F.

The other problems with the air-handling system were encountered and corrected. First, the air handlers were operated by a stop-start button, which could shut off during a power fluctuation. This often happens in remote areas. They must then be restarted manually. Secondly, the heat sensor devices for the lights were not installed correctly. These devices are designed to automatically shut off lights when a certain temperature is reached in the module, so that the plants are not burned. In one instance, when the air-handles went off and the heat sensor devices did not work, a full crop of tomatoes was lost and cucumbers and lettuce were damaged.

4. **Heating System.** One problem was encountered with the supplementary heating elements that are built into the input air ducts of the air handler. Fluctuating power surges at Argentia burned the fusible links that connected the elements. They were replaced with Thermo-Protective Devices.

5. **Lighting System (see Figure 3).** Generally the lighting system worked well except for the safety heat sensor devices. The use of multi-vapor and **Lucalox** lamps worked well. The only bad effects on the plants were some minor burning of plant tops due to the intense heat. It is suggested that the use of lower intensity (500W) bulbs be looked into in order to reduce the cost of electricity. The experiment of shutting some of the lights to save electricity caused a substantial loss in plant yield.

6. **Nutrient System.** The automatic pH and CO_2 controllers did not work at all due to fuses burning out overnight; winddrift and moisture affected the CO_2 readings. It is recommended that for an operation of this size an automatic system is not needed.

Major problems were encountered with the prilled $Ca(NO_3)_2$ which crystallized on the roots and in the tanks. It is recommended that $Ca(NO_3)_2$ in a nonprilled form be used.

The cost of nutrient analysis in Argentia is very high and took a long time to obtain from the private lab; this caused uncertainty in determining the levels of nutrients and in adjusting the ratio of the chemicals. It is suggested, especially in isolated areas such as the Antartic, that a portable plant/nutrient analysis kit be provided on-site as recommended in the Navy's final report on IAU.

7. **Relative Humidity System.** The fogging system of adding humidity to the air proved totally unsatisfactory. It appeared to be undersized for controlling three modules at the same

time. After two motors were burned up, the system was shut down. No major effects were observed on the plants, although a difference in yields was not measured.

8. **Supplies.** Obtaining supplies was difficult since they were not available through normal military supply channels.

9. **Manpower Requirements.** This system of three modules required a minimum of two full-time personnel and a third person for periods of sickness or leave. It is not necessary that they be technically trained since the operation is simple and well laid out. An interested person would be taught the basics and would be able to run the operation without much difficulty.

CONCLUSIONS

1. The results of this experimental test indicate that Hydroponic vegetable production lends itself to successful application at isolated sites utilizing relatively inexperienced personnel.

2. The units tested produced more than enough salad vegetables for 200 persons twice per day.

3. The operating costs to produce all three vegetables as provided by the Navy proved to be higher than those estimates by Ballinger, and the University of Connecticut (see Appendix B). The differences could be caused by several factors including:

   a. Short-term problems in startup and experimentation with the units and growing procedures.

   b. Accuracy and source of the figures reported by the Navy.

   c. Inflation, since the Ballinger and University of Connecticut figures were developed in 1979 and the test results in 1980.

4. Nutritional and morale factors of having high grade salads available each day must be measured. This will be especially true at sites such as "Operation Deep Freeze" Antarctica and on a long-range naval patrol where resupply is difficult or nonexistent.

5. The operation in Argentia required a minimum of two full-time personnel to operate. These people do not necessarily have to have an agricultural background. Interested persons were taught the basics and ran the operation without difficulty.

RECOMMENDATIONS

It is recommended that:

1. Since the unit was tested in a cold climate, it also be evaluated under tropical conditions.

2. The information gathered on the two tests be used in recommending installation of hydroponic units in remote areas of the world.

3. The present test units be permanently installed at a remote side (such as "Operation Deep Freeze" Antarctica) so that it may be fully utilized. The units will have to be refurbished to adapt to the new location.

This document reports research undertaken at the US Army Natick Research and Development Command and has been assigned No. NATICK/TR–82/039 in the series of reports approved for publication.

APPENDICES

A. Final Report on IAU Test Project, Commanding Officer US Naval Facility, Argentia, Newfoundland.

B. An Analysis of the Need and Requirements for, and Alternatives to, Nutriculture as a Means of Providing Fresh Vegetables to DoD Forces in Remote, Inaccessible Areas of the World by Walter E. Ballinger, LTC, QM, USAR Mobilization Designee, US Army Natick Research and Development Command, Natick, MA 01760 and PhD, Professor of Horticultural Science, North Carolina State University, Raleigh, NC 27607.

B–I. Excerpts from Controlled Environment Plant Growth by R.P. Prince, W. Giger, Jr., J.W. Bartols, Fr., and T.L. Logee, Department of Agricultural Engineering, University of Connecticut, Stors, Connecticut 06268.

B–II. Hydroponic Agriculture by Dr. Abdul R. Rahman, US Army Natick Research and Development Command, Natick, MA 01760.

COPY

APPENDIX A

DEPARTMENT OF THE NAVY
U.S. Naval Facility
FPO New York 09597

In Reply Refer To:
NFA:N4:el
11018
Ser: 328

29 April 1980

From: Commanding Officer, U.S. Naval Facility, Argentia, Newfoundland
To: Commander, U.S. Army Natick Research and Development Command, Natick, MA 01760

Subj: Intensive Agriculture Unit (Hydroponics) Project Report

Encl: (1) Final Report on IAU Test Project

1. This command has participated in the field test and evaluation of the Intensive Agriculture Unit (IAU) at Argentia under the guidance of your command from 1 June 1977 to present. Enclosure (1) is a report of this test as requested by reference (a).

2. The overall evaluation must be expressed as highly successful. The quality of the products and the very favorable effect on the morale of the personnel makes the application of this method of vegetable supply most desirable to an isolated location where a ready availability of good vegetables does not exist.

3. The present unit will cease operations at this command on 1 June 1980 and is available for disposition. The units will be packed up in such a manner that the four separate trailer type modules can be shipped to another location with a minimum amount of preparation and dismantling.

4. It is requested that disposition instructions be provided to this command.

BAKER L. PEEBLES

Copy to: CO, NFSSO, Wash. D.C. (w/encl.)

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INTRODUCTION

The U.S. Naval Facility, Argentia, Newfoundland operated an experimental Hydroponics Laboratory under the guidance of the U.S. Army Research and Development Command, Natick, Mass. from June 1978 to June 1980. It encompassed the raising of tomatoes, cucumbers and lettuce in separate modules under a carefully controlled environment, utilizing personnel with no previous background in Hydroponics. A three month initial set up and training period was provided under contract by the General Electric Company.

The results of this experiment are enclosed in this report.

I. CO_2 SYSTEM

a. Infra-Red Analysers

(1) Information: General

Miran — 72
CO_2 Gas Analyzer
Wilks Div.
Foxboro Analytical
140 Water Street
South Norwalk, CT 06856
Tel #203–853–1616
Market Manager: Rick Syrjala
Maintenance: Paul Raspe

(2) Problem:

The CO_2 Source Analyzer Assembly is only good for 6 months at constant usage. Wilks is presently working on this problem and are just about ready to market an improved source assembly which would last approximately 3 to 4 times longer. This system is good now and will be great when Wilks perfects its source assembly.

b. CO_2 Bottles

The cylinder type bottles presently in use are OK but because of bulkiness, it is time consuming to set up a new bottle when one is empty. Presently, we go through 1 bottle every 2 to 3 days. It is recommended that a CO_2 tank be installed outside the building, which would need only to be refilled on a monthly basis.

c. Cost Analysis

(1) Presently the cost of CO_2 per bottle is $21.50.

(2) Since setup in Sep 78, we have used 205 bottles. (This figure would be higher if we did not have problems with the system).

(3) Total cost for period covering Sep 78 to Mar 80 is $5,407.50.

(4) Per day average cost since setup — approximately $10.50.

II. AIR CONDITIONING SYSTEM

a. Thermostat Control — Honeywell

These thermostats are basically OK. They do however, have one minor problem: because of the intense heat from lights in the module, the thermostats have to be covered to shield the light. The heat from the lights make the thermostat read higher than the actual module temperature.

Example — Thermostat Reading — 90°F
Actual Module Temp° — 78°F

b. Air Handlers

Due to a power fluctuation, a crop of tomatoes was destroyed. This, mainly, was due to two problems with the design which have been corrected. The problem with the air handler was that it was operated by a manual stop/start button. When the power fluctuated, the air handler went off and because no one was there, it did not automatically turn back on. By the time it was noticed that the air handlers were down, it was too late. This problem would not have been a disaster if the heat sensor devices for the lights had been installed correctly. These devices are designed to automatically shut lights off when a certain temperature is reached in the module so that the plants are not burned. The devices did not work and we lost a full crop of tomatoes, with damage to cucumbers and lettuce. These two problems have since been corrected.

III. HEATING SYSTEM

Supplementary Heating Elements

The supplementary heating elements that are built into the input air ducts of the air handler have one basic problem — that problem being that because of the fluctuating power surges here at Argentia burn the fusible links that connect the elements together. When ordering these fusible links, use the name: Thermo-Protective Devices.

IV. LIGHTING SYSTEM

a. General

The use of multi-vapor and Lucalox lighting is good. The bad effects on the plants have been limited to just some minor burning of plant tops. This is due to the intense light and the distance between plant tops and lights.

b. **Safety Heat Sensor Devices**

As mentioned in Section II, a problem developed due to improper setup of the devices. Now that they have been installed correctly, they work great. The sensors automatically shut the lights off when the maximum temperature is reached.

Example:	Sensors set at:	88°F
	Lights go off at:	89°F
	Lights on again at:	85°F

NOTE:

Recommend the use of lower intensity (500-w) bulbs. The cost of electricity is high and 500-w bulbs would save money on the electricity bill. The experiment of shutting some of the lights off to save on bill only caused a substantial loss in plant yield.

V. NUTRIENT SYSTEM

a. **Ph & S.S. Controllers**

Kernco Model No.: BC2R–PHC
Kernco Instruments Co. Inc.
420 Kenazo Street, El Paso, Texas 79927
Tel #915–852–3375

This system, to date, still does not work.

Problems:
1. Burns fuses overnight.
2. Wind drift effects readings.
3. Moisture effects readings.

NOTES:

Recommend controllers be sent back to Company for refund.

For an operation of this size, an automatic system is not needed.

b. **Chemicals**

Major Problems

(1) $CaNo_3$ in prilled form.

Side effects – Crystalization of $CaNo_3$ on roots and in tanks. Make sure that you order $CaNo_3$ that is **not in prilled form.**

(2) Supplies – See Section VII – Supplies

c. **Analysis of Nutrients**

The cost of nutrient analysis locally is high. This causes a problem in not knowing if the ratio of chemicals are proper and if the correct levels are being maintained. Suggest a portable plant/nutrient analysis kit be considered. It can be bought through "Brighten-By-Products Inc.".

d. **Topping Tanks**

This system is okay but not needed if a manual system of adding nutrient to the tanks is used.

VI. RELATIVE HUMIDITY SYSTEM

General

The system is totally unsatisfactory. The air pump and air tank are too small for operating the three modules at the same time. This system has been shut down because we have burned up two motors. Since shut down of this system, we have had no major effects on the plants. Recommend it be eliminated.

VII. SUPPLIES

General

This is a major problem for Bases outside the United States. Because of the experimental stage of Hydroponics, the Supply System does not stock materials. Recommend Natick develop a good commercial supply source for materials, in particular nutrients.

VIII. MANPOWER REQUIREMENTS

A unit of this size requires a minimum of two full time personnel with a third person trained to be able to fill in during periods of leave or sickness of the regular personnel. Recommend a working Petty Officer in Charge with one non-rated or striker full time. There is no need to have an MS in charge as the relationship to the Food Service rating is distant. An interested person can be taught the basics and run the operation without difficulty.

IX. COST

The following costs of operation show a variation in maintenance and lamps as one time items initially required during the "de-bugging" phase. An expenditure variation in supplies was due to a full year's purchase of materials in late FY 79 to last throughout FY 80. FY 80 costs are from 1 October 1979 – 1 April 1980 only.

ITEM	FY 79	FY 80
Electricity	$7,102	$3,051
CO_2	$1,550	$1,563
Maintenance	$1,545	180
Telephone	482	155
Supplies	$1,525	360
Lamps	$1,141	0
Misc.	202	0
Total –	$13,546	$5,309

X. YIELDS

The monthly yields in pounds are provided below. Variations in quantities resulted from various experiments, trial methods and equipment failures. Normal operations will provide in excess of 200 salad portions per day for an Enlisted Dining Facility. Consideration should be given to expanding tomato production and reducing cucumbers which are prolific producers. Combination of cucumbers with tomatoes in the same unit proved effective in this test.

MONTH	CUCUMBER	TOMATO	LETTUCE
October 1978	483	5	70
November 1978	563	316	402
December 1978	641	370	353
January 1979	782	332	306
February 1979	464	207	238
March 1979	542	338	441
April 1979	535	167	551
May 1979	337	200	704
June 1979	120	283	540
July 1979	257	215	452
August 1979	417	176	348
September 1979	188	152	220
October 1979	200	149	64
November 1979	241	332	459
December 1979	0	186	252
January 1980	51	91	166
February 1980	156	156	0
March 1980	256	230	144
April 1980 (1–21)	170	77	212

XI. SUMMARY

The results of this experimental test indicate that Hydroponic vegetable production lends itself to successful application at isolated sites utilizing relatively inexperienced personnel. An initial training period is essential and the careful attention to procedures is essential. A complete book of instructions has been prepared in detail and is available with the present unit at Argentia.

Several design problems have been corrected and the unit is capable of continuous production at present.

APPENDIX B

An Analysis of the Need and Requirements for, and Alternatives to, Nutriculture as a Means of Providing Fresh Vegetables to DoD Forces in Remote, Inaccessible Areas of the World.

by

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and

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INTRODUCTION. The United States Navy has established a requirement (USN 5—4) for an Intensive Agriculture Unit (IAU) (AH 99BB068) for isolated shore stations. The remote and inaccessible Naval Facility at Argentia, Newfoundland was chosen as a test site for such a unit. The Navy undoubtedly chose this site for the analysis because of its remoteness and relative inaccessibility; however, it is not too remote and inaccessible. This permits fairly-easy transport of scientific/technical personnel, equipment, and supplies from the contractor and from the United States Army Natick Research and Development Command at Natick, Massachusetts during the test. Also considered was the relatively small size of the facility, 200—400 military personnel.

Argentia, Newfoundland is relatively isolated in respect to access by commercial airline passenger and air-freight services. A check by transportation personnel at the USANARDCOM indicated that no scheduled flights to the Gander, Newfoundland commercial airport originate from the United States or mainland Canada. Only flights from England and Scotland are scheduled.

This modern airport was constructed toward the end of the propeller-driven airplane era. Prop-planes needed to refuel in Newfoundland on the way from populated areas of the United States to those in Europe. The advent of jet airplanes with no requirement for refueling has resulted in little commercial usage of the airport today. Another airport, the international facility at St. John's, has regularly scheduled flights ship to the port of St. John's.

Lettuce was chosen as a fresh vegetable crop to represent other fresh vegetables for the purposes of the study/analysis in this paper. This decision was based upon the availability of relevant technical information[1] plus the fact that leafy vegetables have a high production yield, require a relatively low light intensity, have a high photosynthetic efficiency, and have an excellent acceptability by people in our country.[1] The conclusions from the analysis of lettuce would be applicable to tomatoes and cucumbers, two other crops considered for production in IAU's.

DESCRIPTION OF NEWFOUNDLAND[2,3]

General. Newfoundland is the tenth province of Canada and comprises two areas: the Island of Newfoundland and the Coast of Labrador on the mainland; 156,185 square miles. It lies about 1,000 miles to the Northeast of Boston.

Soils and Vegetation. Much of the interior is marsh and moorland. The Wisconsin glacier removed much of the pre-Pleistocene soil cover and vegetation. True soils have had little time to develop since then. Heavy rainfall leaches out the soluble mineral salts, thus the soil is very acid. Coniferous trees also tend to make the soil acid.

Climate is mariner in character. The influence of the sea is modified by the waters of the Labrador Current which sweeps along the east and west coasts.

The island has a generally favorable climate that is free from extremes of heat or cold. Summers are cool with a mean temperature of 60°F in July, due to the cooling effect of the sea. Warmest weather doesn't arrive until August. Winters, especially in the Avalon peninsula, are relatively mild, begin in December, continue into late March or early April, and have a mean January temperature range of 15 to 25°F. Again, the presence of the sea moderates, preventing the very cold readings of the mid-continental areas.

Precipitation ranges from 40 inches at the Strait of Belle Isle to 50 inches in the southeast. Snowfall varies from 80 inches on the south coast to more than 120 inches in the northern half of the island. In winter the east and west coasts are icebound for five months in the north and for one month in the south. Only the south coast, including the port of St. John's is ice-free throughout winter. High winds are frequent in winter, often bringing fine snow or near the coast, frozen spray. The sky is foggy or overcast at times, the situation being worse in winter than in summer. This overcast, foggy situation was a factor in the selection of Newfoundland as a refueling station for planes in World War II when cover and concealment were important.

[1] Prince, R.P., W. Giger, Jr., J.W. Bartok, Jr., and T.L. Logee, 1976. Controlled environment plant growth. A report submitted to the Environment Committee of the General Assembly, State of Connecticut.

[2] Anonymous. Encyclopedia Americana, 1975. Vol 20, pp 273–281.

[3] Anonymous. Encyclopedia Brittanica, 1971. Vol. 16, pp 335–340B.

Agriculture. The climate is unfavorable and the soil is shallow, rocky, acid, and needs lots of fertilizer and lime. The growing season is short. There is a risk of frost during the growing season. Main crops consist of hay, small fruits, potatoes, cabbage, turnips, and very small amounts of green vegetables. Thus, agriculture is subsidiary to other primary industries.

Transportation and Communications. The island has several seaports. The railway mainly serves the ports. Newfoundland lies on the shortest air-route between the most densely populated regions of North America and Europe but, as mentioned above, is by-passed by most major airlines since advent of jet planes which do not require enroute refueling. Only Air Canada Airways and East Provincial Airways regularly schedule flights in and out of the island.[4]

Water Power is the main power or energy source. By the mid-1960's over 700,000 HP of electrical power was available on the island, with an undeveloped potential of 900,000 HP. Today, however, periods of power shortage exist. The Naval Facility at Argentia has back-up generators. Labrador, the mainland component of "Newfoundland," has one of the largest single power plants in the world, rated at 4,500,000 HP. Water power provides the potential for expansion to at least 9,000,000 HP.

DEFINITION OF THE NEED. Although the per capita consumption of many fresh vegetables has decreased since 1960 in the United States, the consumption of lettuce[1] has increased from 20.0 lb in 1960 to 22.4 lb per person in 1972, the highest consumption rate of any fresh vegetable in the country (Appendix I, Table 5.2). This preference for lettuce was also reflected in a survey of 3890 Air Force, Army, Marine Corps, and Navy personnel, as reported in 1974.[5] Of 378 food items included in the survey, only seven other foods were preferred for consumption more frequently than tossed green salad; only 23 more than lettuce salad, and only 52 more than tossed vegetable salad. On a Hedonic scale of 1 to 9, the above salads were rated 7.03, 6.63, and 6.31, respectively.

Thus, it is easy for one to justify the need for supplying lettuce to DoD personnel in remote areas. The importance of not only having a continuous supply of lettuce, but a continuous supply of high-quality lettuce to these areas was reflected in the comments of the Supply Officer at the Naval Facility at Argentia, Newfoundland in a recent telephone conversation.[6] He stated that he was very enthusiastic about the prospects of having a supply of daily-fresh lettuce and tomatoes available at the facility. He said that, upon his return to the facility after a recent leave to CONUS, one of the most remembered highlights of his leave was the high-quality, fresh lettuce and tomatoes that he enjoyed while on leave. The quality was radically superior to that of the type they had at Argentia.

[4] Correspondence (verbal) with LCDR Helmuth, US Navy, member of Joint Forces Board, USANARDCOM, Natick, MA 01760.

[5] Meiselman, H.L., D. Waterman, L.E. Symington, 1974. Armed Forces food preferences. Technical Report 75–63–FSL, USANARDCOM, Natick, MA 01760.

[6] Telephone conversation by LCDR Helmuth with Supply Officer US Navy Facility, Argentia, Newfoundland.

POSSIBLE MEANS OF SUPPLY

First: Head Lettuce Produced in California and Arizona

A. **Transcontinental shipment** by refrigerated train; weekly flight by **MAC planes from McGuire AFB in New Jersey** to St. John's Newfoundland; plus trucking to Argentia. This system was in operation four or five years ago but has been discontinued.

1. **Estimate of cost** of edible lettuce if this system were used today:

   a. Cost of LETTUCE, FRESH, Iceberg, US No. 1 Grade, two dozen size, packaged individually (National stock no. 00–926–4926; Identification no. 4970)[7] from DPSC at Philadelphia, May 1976: $0.2529/lb

   b. Transport by truck (commercial rates) to McGuire AFB in New Jersey, approximately 25 miles from Philadelphia ($2.04/CWT) is $0.0204/lb

   c. Transportation by AF plane from McGuire AFB to St. John's Newfoundland (see Table 1): $0.1298/lb

   d. Trucking (commercial rate) from St. John's airport to Argentia $0.0325/lb

   e. Estimated overhead at DPSC, McGuire, St. John's, etc., (5% of DPSC cost): $0.0126/lb

   Therefore, the delivered cost: $0.4482/lb

2. **Yield of edible lettuce leaves:**

   a. Normal edible yield of freshly harvested lettuce is 75% (menu cards).

   b. Edible yield of stored lettuce (shipped and stored for four weeks before consumption) is reported to be 61%.[8,9,10]

[7] Anonymous. Federal Supply Catalog (Consolidated), Stock List, FSC Group 89 SUBSISTENCE, 1976. C8900–SL.

[8] Gorfien, H., A.R. Rahman, K.R. Johnson, and E.E. Anderson, 1969. Effects of a controlled atmosphere system on the storage life of lettuce. Part I: Laboratory Tests. Technical Report 70–23–FL, USANARDCOM, Natick, MA 01760.

[9] Gorfien, H., A.R. Rahman, and D.E. Westcott, 1969. Effects of a controlled atmosphere system on the storage life of lettuce. Part II: Field Test. Technical Report 70–26–FL, USANARDCOM, Natick, MA 01760.

[10] Rahman, A.R. and D.E. Westcott, 1970. Quality of lettuce as affected by refrigeration and controlled atmosphere systems during transportation. Technical Report 71–10–FL, USANARDCOM, Natick, MA 01760.

c. Edible yeild of lettuce received at Argentia, as reported by the Supply Officer is 50%.[4,6]

d. Utilizing the average (62%) of the above yields, the cost of the edible (consumable) lettuce is: $0.7229/lb

3. **Quality of this lettuce.** A yield of edible leaves of 50 to 61% (above) instead of the normal 75% (discarding the stem, core, and damaged/decayed outer leaves) indicates an inherently poor quality. the original green, outer leaves of a head of lettuce have a better appearance and are more nutritious than those toward the core of the head. Who would like a tossed yellow salad instead of a tossed green salad? In addition, the nutritional content of the head is known to deteriorate with time after harvest. For example, vitamin C content of lettuce is known to decrease by one-third to one-half within three days at room temperature or after 10 days in cold storage after harvest.

Table 1. Estimation of Cost of Flight of Lettuce from McGuire AFB, NJ to St. John's, Newfoundland

I. Cost of one flight (cost of operation and maintenance only; does not include cost of plane, pilot salary, etc.), C—130 or similar plane (4 hr x $1100/hr): $4400.

II. Capacity of C—130 is 40,000 lb

III. Case of lettuce specifications[7]

a. 24 heads (lb); 27 lb gross/case

b. Dimensions 2.15" L x 14.5" W x 11.5" H

IV. Cargo is palletized. Pallet specs:

a. 108" W

b. Lengths of 8, 12, 16

c. Weight of 8′ pallet is 300 lb

V. Stacking of lettuce cartons on 8′ pallet (96")

a. One layer holds:

(1) 108" W ÷ 21.5" (length of lettuce case) = 5.0 cases W on pallet

(2) 96" L ÷ 14.5" (width of lettuce cases) = 6.0 cases L on pallet

(3) 5 x 6 = 30 cases per layer

b. Number of layers:

(1) Maximum loading height of pallet is approximately 100″

(2) 100″ ÷ 11.5″ (height of lettuce case) = 8.7 cases, or 8 layers

c. Total number cases per pallet load (30 x 8) = 240 cases

d. Total weight of leaded 8′ pallet

(1) Weight of pallet = 300 lb

(2) Weight of crates of lettuce: (240 cases x 27 lb/case) = 6480 lb

(3) Loaded pallet weight = 6780 lb

(4) Net weight of lettuce only per pallet (24 lb x 240 cases) = 5760 lb

VI. Cost to transport 1 lb of lettuce:

a. 5760 lb lettuce per 6780 lb loaded pallet; therefore, 6780 ÷ 5760 = 1.18 lb for each lb lettuce shipped

b. Cost to transport 1 lb of gross on plane: $4400/40,000 lb = $0.11/lb

c. 1.18 lb/1 lb lettuce x $0.11/lb = $0.1298/lb lettuce

Availability. MAC planes were on a regular weekly schedule, but sometimes there was no room for lettuce on the plane. Therefore, lettuce supply was unpredictable. Week to week storage ties up valuable refrigerated space that could be used for storage of other perishables.

Second: Delivery by Navy Ship. Since supply ships to Argentia arrive each six weeks,[6] this course of action can be eliminated immediately without a need for comparison with other courses of action. Even with the use of fungicides and controlled atmosphere storage,[8,9,10] lettuce cannot be stored satisfactorily for more than four or five weeks.

Third: Delivery by Commercial Airlines.

1. **Cost/lb** of edible leaves of lettuce:

a. Air Canada has flight at 10 a.m. daily from Boston to St. John's airfield in Newfoundland. Maximum amount of lettuce Air Canada will accept per flight is 500 lb. Rate per lb cargo is $0.2550.

b. Cost of lettuce (DPSC HQ; May 1976 price) 0.2529/lb

c. Trucking to Boston airport (est) 0.0204/lb

d. Air freight from Boston to St. John's 0.2550/lb

e. Trucking to Argentia 0.0325/lb

f. Total delivered gross weight cost $0.5608/lb

g. Crates weigh 3 lb; therefore, cost of lettuce itself is $0.5608/lb x 27 (weight of crated lettuce) ÷ 24 (weight of lettuce only) $0.6309/lb

h. Cost of edible leaves of lettuce ($0.6309/lb x 100 ÷ 75% yield) $0.8412/lb

2. **Quality** of this lettuce, if flown in daily, would probably be better than that of lettuce supplied to Argentia to date. However, there is the potential for lower quality upon delivery if the lettuce sits around at warm temperatures for any length of time at either airport, waiting for subsequent transport. Experience with air shipment of fresh produce by the United States Department of Agriculture indicates that only one out of three hours of "shipment" time is actually spent in the air.

3. **Availability** of lettuce flown in daily would be much better than that of lettuce supplied at weekly or multi-week intervals.

Fourth: Delivery by Local Contractor. Head lettuce is presently being supplied by a local contractor. It undoubtedly originates in California and/or Arizona.

1. **Cost/lb** of edible leaves of lettuce:

a. Purchase price of heads of lettuce: $0.300/lb

b. Trucking (commercial CONUS rate) from St. John's Argentia: 0.0325/lb

c. Total delivered gross-weight cost: $0.3325/lb

d. Cost of edible leaves ($0.3325/lb x 100 ÷ 62%; yield for three to four week old lettuce): $0.5363/lb

2. **Quality.** Since the Supply Officer at Argentia reported by phone[6] that they sometimes have to discard 50% of the leaves of the heads of lettuce that they currently receive from the contractor, the quality of the remaining portion of the heads is undoubtedly as poor as that of lettuce formerly received via the MAC flights from McGuire AFB. In fact, the Supply Officer rated the quality of their lettuce at 2 to 3 on a scale of 1 to 10 (10 being the highest quality).

3. **Availability** is no problem, according to that Naval Supply Officer at Argentia.

Leaf-Type Lettuce Produced at Argentia. Climatic and soil conditions in Newfoundland[2,3] do not permit an adequate production of fresh vegetables in the field either on a seasonal or on a year-round basis. Therefore, this source of lettuce is not included in this paper. The other alternatives for local production are controlled environment plant growth units IAU (Intensive Agriculture Units) and greenhouses. These facilities involve large initial capital investment for buildings and equipment. They also require the expenditure of large amounts of energy for temperature control and light for plant growth. In order to justify these great expenditures, hydroponics or nutriculture is utilized in lieu of standard "soil-culture." A description, history, and discussion of **Hydroponic Agriculture**, authored by Dr. A.R. Rahman, is attached as Appendix II. The reader is encouraged to read Appendix II before continuing.

Leaf lettuce production is well adapted for IAU or nutriculture on a commercial scale because of its compact size, photosynthetic efficiency, and high yield per square foot of growing surface. Eighty-five percent of the plant is edible. Only the roots are not consumed. Few crop production operations (plant the seed, transplant the seedlings, and harvest) are required. Leaf lettuce was thought to have such a high potential for production under controlled-environment conditions that the legislature of the State of Connecticut appropriated $50,000 to the University of Connecticut[1] for a detailed study of the feasibility of growing leaf lettuce. The summary and pertinent cost-figure tables from the resulting report is included as Appendix I. The report is one inch thick and represents the efforts and contributions of many people, including a six-member advisory committee and five consultants. These included world-famous specialists from the Light and Growth Laboratory, USDA, ARS, Beltsville, MD and an agricultural engineer from the Transportation and Packaging Laboratory, AMRI, USDA, ARS, Beltsville, MD. Fr. T. Gaucher, former owner and operator of Aquafarms, Lebanon, CT provided practical growing information useful in the design of a "proof-of-concept" unit and its operation. Westinghouse Electric Co. and the Connecticut Light and Power Co. provided light bulbs and watt-meters. Two researchers from the Connecticut Agricultural Experiment Station put in full time for one year. The Orrs Agricultural Expt. Station and the University of Connecticut Research Foundation provided supplemental funding to increase total expenditures (other than manpower) to $63,000. At least 12 people, such as accountants, bookkeepers, students, etc., were utilized. Thus, this was a significant undertaking. Their findings constitute an extremely important source of information. The system they developed and analyzed was termed "CEPG" (controlled environment plant growth).

Another source of information on controlled environment plant growth is the General Electric Corporation. After years of research and development, they developed a commercial production system called "Geniponics."[11] GE is testing this system at Syracuse, New York. A comparison of the advantages of the Connecticut and General Electric systems over standard field (California and Arizona) and greenhouse production of lettuce in Connecticut is as follows:

[11] Anonymous, 1975. GENIPONICS,™ a programmed environment agricultural system; EHM–12, 157; REV 5(1–75). General Electric, Electronic Systems Division, Syracuse, NY.

Type of Production	Yield lb/ft² /yr		Ratio of Yields		Crops/yr (no.)		Cost of prodn. ($/lb)	
	Conn	GE	Conn	GE	Conn	GE	Conn	GE
Field	2	1.5	1	1	4	3	0.20–.23[a]	b
Greenhouse	4	3	2	2	5	4	0.25–.28[c]	b
Controlled environ.	73	90	36	60	11	12	0.25–.38[c]	b

[a]Delivered to east coast; [b]Data not available; [c]Include $0.02/lb for a shipping container for fresh-marketing.

These data from two highly-different sources (a state agricultural experiment station and a commerical manufacturer) indicate the tremendous potential for producing large quantities of lettuce in a relatively small space. One would assume that the cost of production of a pound of lettuce by the GE Geniponic unit would approximate that of the Connecticut CEPG system.

A. **Controlled environment plant growth (CEPG) units.**

1. **Cost.** The cost of a pound of edible leaves from leaf lettuce produced in CEPG unit and delivered to a nearby mess-hall would very closely approximate the cost of production. Costs of shipping containers (2¢/lb), transportation, brokerage fees, etc., would be eliminated since lettuce would be taken daily from the CEPG to the mess-halls. Little if any loss in yield would occur during preparation for salad usage in the mess-halls because leaf lettuce, compared to head lettuce, has little core or stem tissue. Cost of production in Argentia, Newfoundland would probably be higher than that reported in Connecticut, depending upon the cost of energy at Argentia. Costs of electrical power, fuel oil, gasoline, labor, fertilizer, etc., used in the Connecticut study are given in Table 10.2 of Appendix I. Estimated cost/lb of edible lettuce, assuming costs equivalent to those in the Connecticut study is $0.25–0.38/lb.

2. **Quality.** What better quality could be had than that of lettuce harvested and consumed the same day? How many people prefer a vine-ripened tomato picked in their won garden and consumed the same day to one picked while green and shipped/stored for weeks.

3. **Availability.** Excellent.

B. **Combination of CEPG and greenhouse.** The Connecticut report indicated that 93.5% of the energy consumed by the CEPG was for plant-growth lights and air conditioning Appendix I, Table 10.5. The CEPG required the use of 10 times as much energy as that used for field production (35,773 versus 3,467 Btu to produce 1000 lb of lettuce). Consequently, the authors of the Connecticut report stressed the importance of finding some means of using renewable energy sources. Or, instead of using energy for air conditioning which in turn removes and

wastes large amounts of heat produced by the lights in the CEPG, they thought that perhaps the waste heat from the CEPG lights could be used to heat other nearby facilities that required temperature control. Indeed, they constructed a hybrid CEPG and greenhouse unit that utilized the heat from the lights in the CEPG to heat the attached greenhouse. This eliminated the requirement for air conditioning the CEPG and a furnace and fuel to heat the greenhouse.

1. **Cost.** Lettuce produced by this hybrid system required much less energy than that required by a CEPG plus a separate greenhouse. The cost of producing lettuce in the hybrid unit (16–20¢/lb) was highly competitive with the cost of California field lettuce delivered on the east coast (20–23¢/lb).

2. **Quality.** Since lettuce produced by the hybrid unit is harvested and consumed daily, its quality would be as good as any that can be obtained.

3. **Availability.** Excellent; daily supply of freshly-harvested leaves.

C. **Greenhouse production.**

1. **Cost.** According to General Electric figures,[11] yield of lettuce produced per year in greenhouses is not appreciably higher than that produced in the fields. High costs of operation of a greenhouse would make such lettuce more expensive. A report from the University of Connecticut indicates that leaf lettuce grown in greenhouses there cost 25–38¢/lb.

2. **Quality** of lettuce grown in greenhouses and harvested daily would be excellent, much better than the quality most people in our country enjoy today. The nutritional value of this fresh daily lettuce would be excellent also.

3. **Availability** of locally-grown greenhouse lettuce would be excellent, and daily.

COMPARISON OF SOURCES OF LETTUCE. A summary of the costs, quality, and availability for each of the fore-going sources of lettuce is given in the following tabulations:

I. California/Arizona head lettuce delivered to Argentia:

Source	**Cost (Cents/lb of edible leaves)**	**Quality**	**Availability**	**DoD operator required**
McGuire AFB plane	72	Very poor	Variable	No
Navy ship	(a	Poor	Variable	No
Commercial airline	84	Fair	Good	No
Local contract	54	Very poor	Good	No

(aData not obtained.

II. Leaf lettuce produced at Argentia, Newfoundland:

Source	Cost[a] (Cents/lb edible lb) 1–X energy $	2–X energy $	Quality	Availability	DoD operator required
Greenhouse	23–26	32–35	Excellent	Excellent	Yes
CEPG	23–36	35–48	Excellent	Excellent	Yes
CEPG/GHSE hybrid	14–18	20–24	Excellent	Excellent	Yes

[a]Estimates from Connecticut study.[1] Costs in left column (1–X energy $) reflect cost of lettuce when the price of energy used in its production is the same as that used to produce lettuce in the Connecticut study (Table 10.5 of Appendix I). Costs in the right column (2–X energy $) reflect the price of producing lettuce when the price of energy is double that used in the Connecticut study. All figures reflect a reduction in the Connecticut costs of 2¢/lb because the need for shipping packages[1] was eliminated.

According to the tabulations above, the **cost/lb** of **edible** lettuce (leaves) grown in California/Arizona and delivered to the mess-halls at the Naval Facility at Argentia, Newfoundland is higher than the projected cost/lb of edible leaf-lettuce produced and consumed at Argentia (according to cost figures developed during the Connecticut study).

The **quality** and **availability** of leaf lettuce, if produced at Argentia, would certainly be excellent and generally superior to the very poor to fair quality of imported head lettuce. A doubling of the energy costs in Argentia would increase the cost of producing lettuce there by 9¢ (greenhouse), 12¢ (CEPG), and 6¢ (CEPG/GHSE hybrid) per pound (Tabulation II above). However, several factors should be considered or investigated before or during the R&D.

First, Ellis, et al[12] stated several disadvantages of nutriculture. They included: (a) "Trained plantsmen must conduct the growing operation. Knowledge of how plants grow and the principles of nutrition are important," (b) "The reaction of the plant to good or poor growth is unbelieveably fast. The grower must observe his plants every day," and (c) "Introduced soil-borne diseases and nematodes may be quickly spread to all beds on the same nutrient tank of a closed system." In essence, the comments of Ellis, et al[12] reflect the opinion of many plantsmen and the plant scientists who have had considerable experience with plant production in nutriculture. In the field or garden, one can till the soil, plant the seed, fertilize, and possibly much neglect the plant other than an occasional cultivation until time of harvest, and still obtain some degree of yield and quality. In nutriculture, however, neglected plants would surely perish long before time of harvest and yield nothing but expenses. The plants would be subject to potential infestations of pathogens, insects and mites; to failure of adequate oxygenation of the nutrient solutions; and man-adjustment of the individual nutrient contents

[12] Ellis, N.K., M. Jensen, J. Larsen, and N.F. Oebker, 1974. Nutriculture systems, growing plants without soil. Agriculture Experimental Station Bulletin No. 44, Purdue University, West Lafayette, Indiana.

of the nutrient solutions. The real value of a trained plantsman observings his plants daily is the detection of early development of divergence from health plant status and the initiation of immediate corrective action, before appreciable damage to the crop occurs.

One must remember that the Connecticut study was conducted using the very best consultants available in the country, including the manager/owner of a commercial hydroponics farm. General Electric has an impressive group of plant and electronics specialists developing their nutriculture units.

Where would DoD obtain the service of trained plantsmen to operate its nutriculture units in remote areas? Perhaps personnel records could be screened to locate persons with a degree in horticulture or related plants discipline and plant nutrition. Such persons would still require specialized training in intensive agriculture. As an alternative, civil service might be a medium through which suitably trained and experience persons could be located, trained, and utilized. Such a person would preferably be employed at the GS—11 level or higher so as to attract qualified applicants. A civilian operator might in fact be more desirable than a DoD person since the responsibilities of the plantsman should require no diversional or additional duties. KP, duty as CQ or Officer of the Day, and so forth, would not be compatible with operation of an Intensive Agriculture Unit.

Cost of production of lettuce or green vegetables in Argentia can perhaps be reduced if heat from the light bulbs in the IAU were utilized to heat another facility. This would be doubly efficient since the operation of the air conditioner in the IAU would be reduced or eliminated. The furnace and fuel in the other facility would likewise be eliminated. This philosophy was utilized during the Connecticut study whereby the heat from lights in the CEPG unit was used to heat an attached greenhouse that also produced lettuce. Their resulting "hybrid" unit produced lettuce at a cost that was very highly cost-competitive with California lettuce delivered to the east coast. If the use of greenhouses in Argentia is not feasible, perhaps because of heavy snowfall, overcast skies (low intensity light), or inadequate day-lengths (photoperiod variations with season), perhaps a nearby or contiguous mess-hall, day-room, warehouse, etc., could be heated. The elimination of the energy cost to operate the air conditioner in the CEPG unit in the Connecticut study would have reduced the cost/lb of lettuce by 3¢(Table 10.5, Appendix I) (892.71 KWHR x \$0.033/KWHR = \$29.46/1000 lb lettuce or \$0.03/lb). If the cost of energy in Argentia were double that used in the Connecticut study, the savings would be 6¢/lb of lettuce, an appreciable reduction in cost.

Table 2. Calculation of the energy consumption required for production (fuels for field equipment only) and transportation of California/Arizona head lettuce to Argentia, Newfoundland; plus calculation of energy consumption (electricity used for growth of plants only) for production of leaf lettuce in an Intensive Agriculture Unit in Argentia.

I. California/Arizona field lettuce.

A. Production (fuels only; refer to Table 10.5 of appendix):

1. 1.40 gal diesel fuel (138,800 Btu/gal)[13,14] = 194,320 Btu

2. 0.59 gal gasoline (125,000 Btu/gal)[13,14] = 73,750 Btu

3. 0.14 gal LP gas (92,000 Btu/gal)[13,14] = 12,880 Btu

4. 6.09 cn ft natural gas (1,031 Btu/cn ft) = 6,279

5. Total energy consumption/100 lb lettuce = 278,299 Btu

6. Energy consumption/lb lettuce = 287 Btu

B. Transportation to Argentia.

1. Truck (1.4 Btu/mile x 24 miles)[13] to railhead 35 Btu/lb

2. Rail from L.A. to Boston (0.334 Btu/mile x 3052 miles)[13] = 1,022 Btu/lb

3. Plane from Boston to St. John's (11.0 Btu/mile x 100 miles)[13] = 11,000 Btu/lb

4. Truck from St. John's to Argentia (0.335 Btu/mile x 25 miles)[18] = 35 Btu/lb

5. Total energy for transportation = 12,127 Btu/lb

II. Leaf lettuce produced in an IAU at Argentia.

A. Electricity consumed in production (refer to Table 10.5, Appendix I) (uses of electricity for processing, packing, etc., not included since Argentia lettuce does not have to be shipped).

1. Light bulbs	2241.00 kWh
2. Air conditioning	892.71 kWh
3. Fans, etc	1.04 kWh
Total kWh used	3134.74/1000 lb lettuce

[13] Hirst, E., 1973. Energy intensiveness of passenger and freight transport modes, 1950–1970. Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830.

[14] Samples, D.K., 1974. Energy in the automobile. Publication unknown. A Report (see Mr. John Swift, USANARDCOM for copy).

B. Conversion of kWh to Btu.

1. 3413 Btu/kWh

2. 3134.75 Btu/1000 lb x 3413 Btu = 10,698,901 Btu/1000 lb lettuce

3. Btu/lb lettuce = Btu/1000 lb ÷ 1000 = 10,698.0 Btu

On an energy consumption basis (Table 2), the production of head lettuce in California, according to data in Table 10.5 of Appendix I, requires the expenditure of 287 Btu/lb of head lettuce. Transportation of lettuce by rail to Boston (1022 Btu/lb) and by air to St. John's (11,000 Btu), plus trucking to the railhead in California (35 Btu) and from St. John's to Argentia (35 Btu) expends a total of 12,092 Btu/lb. Total energy expended upon delivery to mess halls in Argentia would therefore be 12,379 Btu/lb of "head" lettuce. Correcting for yield of edible leaves (62% as used previously) gives 19,966 or roughly 20,000 Btu/lb of edible lettuce leaves.

Energy consumption (electricity only) for production of leaf lettuce in an IAU at Argentia would be 10,699 or roughly 10,700 Btu/lb of edible leaves. This is roughly half the energy required to produce and deliver California lettuce. These figures do not include materials, equipment, buildings, manpower, etc., involved in production of the lettuce. Energy consumption for shipment of lettuce from Boston to St. John's Newfoundland by ship was not calculated since six-week intervals between trips would not be an acceptable means of supplying lettuce to Argentia.

CONCLUSIONS. From a cost, quality, availability, and energy consumption standpoint, production of leaf lettuce in an Intensive Agriculture Unit at US Naval Facility at Argentia, Newfoundland appears to be highly feasible.

RECOMMENDATIONS. That research and development of an IAU at Argentia be initiated immediately. Morale and nutrition of personnel there would be materially enhanced.[6]

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APPENDIX B–1

EXCERPTS FROM

CONTROLLED ENVIRONMENT PLANT GROWTH

A Report
Submitted to:

The Environment Committee
of
The General Assembly, State of Connecticut

by

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April 1976

SUMMARY

The 1974 Legislature of the State of Connecticut appropriated $50,000 to the Department of Agricultural Engineering at the University of Connecticut for a one-year study of the engineering and economic feasibility of producing certain vegetable crops under controlled environmental conditions, all year-round and near heavily populated areas. This included the evaluation of a pilot plant as a production unit and an identification of the kinds and amounts of renewable sources of energy needed for commercial operation.

Growers in New England supply only 12 percent of the regional consumption of vegetables. Local lettuce accounts for about 1 percent of the consumption; tomatoes, 33 percent and cabbage, 45 percent. The short growing season, the availability of year-round "imported" vegetables coupled with an uncertain market are some of the reasons for low production of vegetables in New England. This places Connecticut at the end of the production, transportation and distribution chain which is subject to a variety of disruptions. Hence the decision to investigate the feasibility of producing lettuce locally on a year-round basis by the Controlled Environment Plant Growth (CEPG) system.

Plants produced by the CEPG method are grown in a totally enclosed chamber in which the environmental conditions such as air humidity and temperature, or the type of electric lights used, are controlled to maximize plant production. The operation of the growth chamber is independent of outdoor conditions.

Although most types of vegetables may be grown in a CEPG unit, leafy vegetables having a high photosynthetic efficiency, a high yield, good market potential and requiring low light intensity were factors in crop selection. Leaf lettuce, Grand Rapids variety, was selected for this pilot project.

The study was divided into two major areas: (1) design, construction and operation of a proof-of-concept unit and (2) an engineering economic review. **The proof-of-concept unit**, housed in a remodeled vegetable storage structure, consisted of three shelves 4 feet wide by 24 feet long, stacked vertically 18 inches apart over a tank containing nutrient solution. Fluorescent lights were installed over each shelf. Provision was made for CO_2 enrichment. Commercially available timers, thermostats and controls were used to maintain temperature, humidity and light levels. Devices to space the plants as they grow were incorporated into the CEPG system and have increased the space and light utilization. It is anticipated that the complete CEPG system will yield 70 lbs. per sq. ft. per year of lettuce compared to 4 lbs. per sq. ft. per year for a greenhouse.

Progress has been made toward finding a solution to the problem of supporting each plant from seed-to-harvest to insure the success of mechanical spacing. Plants were very sensitive to the time of nutrient flow, dissolved oxygen in the nutrient solution, germinating temperature, root zone environment, etc.

A cost analysis of four lettuce production systems was made. Conventional cost accounting methods were used which included a 9 percent interest rate for capital. The hybrid system was assumed to be a CEPG unit working in unison with a greenhouse fitted with single layer variable plant spacing benches. The calculated production costs are:

Field grown California head lettuce delivered to Eastern markets	20–23¢/lb.
Greenhouse grown leaf lettuce	25–28¢/lb.
CEPG leaf lettuce	25–38¢/lb.
Hybrid unit (CEPG–Greenhouse) leaf lettuce	16–20¢/lb.

The analysis did not account for a possible lack of acceptance of leaf lettuce in the market place particularly during winter months. Further, it did not attempt to forecast changes in price structure or marketing practices.

Because of the large amounts of electrical power needed for the CEPG system, renewable energy sources and utilization techniques need to be developed. Energy requirements and production costs for the hybrid system and other similar systems need to be evaluated further. New methods of energy conservation should be found and renewable energy sources need to be developed.

In Connecticut approximately eight million square feet of unused factory building space is available, which might be suitable for CEPG units. However, the more economical hybrid unit, consisting of a CEPG unit and a greenhouse, could only use space where a greenhouse could be installed. This limits the usefulness of some factory buildings.

The following conclusions and recommendations can be made:

1. The CEPG concept incorporating variable plant spacing is technologically feasible.

2. The CEPG system is comparable to the standard greenhouse in cost of production. These systems are not competitive with California grown lettuce. The combination greenhouse and CEPG unit appears to be very competitive.

3. Further work is justified to demonstrate the cost effectiveness of the hybrid growing system for leaf lettuce.

4. Increase the yield in the CEPG system from the present 24 to the projected 70 lbs. per sq. ft. per year to refine the operating procedure.

5. Complete the development of the plant support device and plant spacing mechanism and evaluate the plant growth-machine interaction.

6. Lettuce from the proof-of-concept unit should be marketed to determine consumer acceptance.

7. Initiate studies to evaluate renewable sources of energy on the hybrid plant growing process.

Table 5.2

Vegetable Consumpton – Per Capita

Pounds per Year – Person (20)

National Averages

Year	Fresh Vegetables	Lettuce	Celery	Cucumbers	Spinach
1960	105.7	20.0	8.0	2.9	0.9
1961	103.7	20.3	7.7	3.0	0.8
1962	101.3	20.5	7.2	2.8	0.7
1963	101.2	21.4	6.9	3.1	0.7
1964	98.6	21.0	6.8	3.0	0.6
1965	98.3	21.7	6.7	3.1	0.6
1966	95.9	21.6	6.9	3.0	0.6
1967	98.2	22.1	6.8	3.1	0.6
1968	101.2	22.5	7.2	2.9	0.6
1969	97.9	22.1	7.2	3.1	0.4
1970	98.5	22.8	7.1	3.2	0.3
1971	99.2	22.6	7.3	3.1	0.5
1972	98.3	22.4	6.9	3.3	0.5

Table 10.1

Space and Production Data Used in Comparing the Field, Greenhouse (GHSE), Controlled Environment Plant Growth (CEPG) and the Hybrid (GHSE–CEPG) Lettuce Growing Systems

				Hybrid Unit[3]	
Description	**Field[1]**	**GHSE[2]**	**CEPG[3]**	**GHSE**	**CEPG**
Planting Rate – plants/day	2,016	2,016	2,016	1,008	1,008
Days to Harvest	60	45[4]	31	45[4]	31
Number of Crops per Year	4	5	11	6	11
Average Space per Plant – sq. in.	288	64	10.3	10.3	10.3
Space Required per Day – ft.^{2}	4,032	896	144.2	72.1	72.1
Space Required per Crop-Acres/ft.^{2}	5.55A	0.92A	4,470.2	3,244.5	2,235.1
Production per Crop – Plants	83,207	68,040	59,371	43,092	29,686
– Pounds	122,100	34,020	29,686	21,546	14,843
Production per Year – Plants	336,878	340,200	653,083	258,552	326,542
– Pounds	488,400	170,100	326,542	129,276	163,271
Production – Tons per Acre – yr.	44	85	1,591	868	1,591
	2.02	4.24	73.05	39.84	73.05

[1] Based on California head lettuce, 12 x 24 in. spacing and 11T/A yield. (Cervinka, et al. (42) and Knott (22)).

[2] Based on Connecticut conditions, 8 x 8 in. spacing and 17T/A yield. (Bartok (47), Wittwer et al. (49) and Short (48)).

[3] Based on this work

[4] Average for the year; 53 days in winter and 38 days in the spring and fall.

Table 10.2 Rates and Factors Used in Determining Costs

Item	Rate or Factor
Gasoline	50¢ per gal.
Diesel	40¢ per gal.
Fuel Oil (No. 2)	40¢ per gal.
L P Gas	44¢ per gal.
Natural Gas	.42¢ per cu. ft.
Electricity	3.3¢ per KWHR
Seed and Medium	.1¢ ea.
Seed Tape	.1¢ ea.
Water	25¢ per 1,000 gal.
Labor	$5.00 per hour
Fertilizer (10–10–10)	7¢ per lb.
Buildings	
Metal	$4.00 per sq. ft.
Greenhouse w/furnace	$2.50 per sq. ft.
Greenhouse w/o/furnace	$2.00 per sq. ft.
Machinery storage	$2.50 per sq. ft.
Processing	$6.00 per sq. ft.
Packaging Material	2¢ per lb. lettuce
KWHR	3,413 Btu energy equivalent
1 Electric Motor Horsepower	1 KW
1 Ton of Refrigeration	1 Horsepower
Fertilizer Applied	Used by Crop (54)
Field	65%
GHSE	80%
CEPG	80%

Table 10.3

Investment in Buildings Used in Comparing the Four (4) Lettuce Growing Systems

Description	Field	GHSE	CEPG	Hybrid Unit GHSE	Hybrid Unit CEPG	Total
Machinery Storage						
Area – ft.[2]	300	–	–	–	–	
Cost – @ $2.50/sq.ft.	$ 75[1]					
Growing						
Area – ft.[2]		32,670	4,116	3,600	2,416	6,016
Cost – @ $2.50/sq.ft.		$81,675				
– @ $4.00/sq.ft.			$16,464	2	$ 9,664	$ 9,664
– @ $2.00/sq.ft.				$7,200[2]		$ 7,200
Processing and Storage						
Area – ft.[2]	384	384	384	192	192	384
Cost – @ $6.00/sq.ft.	$2,304	$ 2,304	$ 2,304	$1,152	$ 1,152	$ 2,304
Total Cost	$2,379	$83,979	$18,768	$8,352	$10,816	$19,168

[1] Usage factor of 0.1 applied to all field equipment and storage.

[2] Does not include a heating system.

Table 10.4

Equipment Investment Used on Comparing the Four (4) Lettuce Growing Systems

Description	Field	GHSE	CEPG	Hybrid Unit GHSE	Hybrid Unit CEPG	Hybrid Unit Total
Field Machinery (tractor, plow, disc, etc.)	$4,156[1]	$400[2]				
Electrical						
Service Entrance			$3,600		$2,400	$2,400
Lighting ($0.10/Watt plus labor @ 1/2 lamp cost)			$20,079	$2,640	$9,118	$11,758
Shelves, tracks, racks, spacers, etc.			$8,000	$6,300	$6,000[3]	$12,300
Ventilation (fans, controls, etc.)		[4]	[5]	$760		$760
Nutrient solution (pumps, pipe, etc.)			$2,320	$1,160	$1,160	$2,320
Furnace		[4]		[6]		
Propagation shelves	[7]	$5,528	[8]	[9]	[8]	
Processing (inspection, packaging, etc.)	$5,800	$5,800	$5,800	$2,900	$2,900	$5,800
Air Conditioning	$2,350	$2,350	$29,000	$1,175	$1,175	$2,350
Quality Control (light, nutrient, air)			$9,000	$4,500	$4,500	$9,000
Irrigation (well, pump, pipe, etc.)	$4,400	$2,400				
Miscellaneous (+10%)	$1,671	$1,648	$7,212	$1,944	$2,725	$4,669
Total	$18,377	$18,526	$79,317	$21,379	$29,978	$51,357

[1] Usage factor of 0.1 applied to field equipment.
[2] Rototiller.
[3] Includes 2 shelves to propagate seedlings for greenhouse.
[4] Part of greenhouse cost.
[5] Part of air conditioning system.
[6] Heated by CEPG unit.
[7] Seeded directly using seed tape.
[8] Included in the design of the CEPG unit.
[9] Combined with the CEPG unit of the hybrid system.

Table 10.5

Energy and Materials Costs per 1,000 Pounds of Lettuce for the Four (4) Growing Systems Based on a Planting Rate of 2,016 Plant per Day (Divide the table cost by 1,000 to obtain the per unit cost)

				Hybrid Unit		
Description	**Field**[1]	**GHSE**	**CEPG**	**GHSE**	**CEPG**	**Average**
Petroleum						
Diesel – gal.	1.40					
Gasoline – gal.	0.59	1.30				
Fuel Oil, No. 2 – gal.		186.11				
LP Gas – gal.	0.14					
Natural Gas – cu. ft.	6.09					
Cost	$3.48	$75.09				
Electricity						
Lighting – KWHR	2.46	373.31[2]	2,241.00	588.00	2,241.00[3]	1414.00
Air Conditioning – KWHR			892.71[5]			
Fans, pumps, etc. – KWHR		85.71[4]	1.04	1.04	1.04	1.04
Processing – KWHR	13.72[6]	3.32[7]	3.32[7]	3.32	3.32	3.32
Cost	$0.53	$15.25	$103.56	$19.55	$74.10	$46.82
Fertilizer[8]						
Commercial (10–10–10) – lbs.	15.55	11.66	11.66	11.66	11.66	11.66
Cost	$1.09	$0.82	$0.82	$0.82	$0.82	$0.82
Seed and Growing Medium – Units	980.00[9]	2,645.00[10]	2,105.00[11]	2,105.00	2,105.00	1,105.00[11]
Cost	$0.98	$2.64	$2.10	$2.10	$2.10	$2.10
Water – gal.	18,562.00	9,003.00	577.00	577.00	577.00	1,579.00
Cost	$0.64	$2.25	$0.14	$0.14	$0.14	$0.14
Packaging Materials – Units	690.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00
Cost	$13.80	$40.00	$40.00	$40.00	$40.00	$40.00
Total Cost	$24.52	$136.05	$164.62	$62.61	$117.16	$89.88[12]

[1] Based on California head lettuce energy requirements for crop establishment, cultural practices, harvesting, transport and processing.

[2] Production of seedlings to 21 days under 30 watts per ft.^{2} artificial light.

[3] Includes 2 shelves to produce seedlings for GHSE for production of 21-day old seedlings. Energy charged to GHSE.

[4] One air change per min. ventilation rate, 1/2 HP burners per 2,000 sq. ft. calculated at 75 percent electrical efficiency (1,000 watts per HP).

[5] Coefficient of performance = 2.51.

[6] Includes hydrocooling.

[7] Includes refrigerated cooler, heat sealer and bagging machine.

[8] Value given for a complete fertilizer, 10–10–10 equivalent.

[9] Seed tape use for direct seeding.

[10] Seedings grown in beds of artificial mix for 21 days.

[11] Seeded in a cup of artificial growing medium.

[12] Represents an average cost per pound for the combined system.

Table 10.7

Calculated Annual Operating Cost for the Four (4) Systems (cents per pound)

				Hybrid Unit		
Description	Field	GHSE	CEPG	GHSE	CEPG	Average
Energy and Materials (Electricity, fuel, fertilizer, packaging, seed, etc.)	2.4	13.6	14.6	6.3	11.7	9.0
Labor[1] (Seedbed preparation, seeding, moving racks, fertilizing, spacing plants, harvesting, inspecting, packaging, etc.)	4.0	7.1	5.2	5.6	5.2	5.4
Depreciation[2] (Building and Equipment)	0.7	4.2	4.6	3.2	3.6	3.4
Taxes, Interest and Insurance[3] (Building and Equipment)	0.3	3.3	1.7	1.3	1.5	1.4
Maintenance[4] (Building and Equipment)	0.2	1.4	1.1	0.7	0.9	0.8
Total (Packaged and ready for Shipment)	7.6[5]	29.6	26.0	15.9	21.7	18.8

[1] Labor rate calculated at $4 per hour plus 25 percent fringe and overhead = $5 per hour.

[2] Straight line method used with a 10 percent value at the end.
Equipment — 5 year life
Building — 20 year life

[3] Calculated at $11.10 per $100 (9 percent interest, $60 per 1,000 on 60 percent assessment taxes and $3 per $100 insurance rate).

[4] Calculated at 8 percent and 4 percent of one-half of the initial investment for equipment and buildings, respectively.

[5] Does not include transportation to Eastern markets (4.9¢/lb. rail, 1972 price, Cargill and Garrett (41)).

APPENDIX B–II

Hydroponic Agriculture

by

Dr. Abdul R. Rahman

What is Hydroponic Agriculture?

Hydroponic Agriculture, also called hydroculture, intensive agriculture and nutriculture, is the growing of plants without soil, using a waterborne nutrient solution. The plants grown under this system are placed in gravel or sand beds approximately 12 inches deep. They draw the needed nutrients from a solution containing all necessary elements. This solution is constantly pumped through the beds. Atmospheric factors, such as temperature, light, moisture are held under close control. The nutrient solution and range of tolerance for most plants is, in parts per million, as follows:

NUTRIENTS IN SOLUTION

Range of Tolerance for Most Plants

	Max.	Min.		Max.	Min.
Nitrate	200	1000	Iron	0.5–2	—
Ammonium	—	100	Boric Acid	0.2–1	5
Phosphorus	30	100	Zinc	0.2–2	20
Magnesium	25	150	Copper	0.1–2	5
Sulfate	150	1000	Cobalt		
Chloride	30	600	Fluoride		
Sodium	—	400	Molybdenum		

These nutrients are commercially available in powder form under different brand names. They differ slightly in composition. The pH of the solution should be controlled in the vicinity of 6.5 for best results.

The nutrient solution can be either circulated through the bed where the plant roots are suspended or it can be spoon fed by sprinkling at pre-set time intervals (Trickle Irrigation System) to accommodate the plant needs. The beds can be made from 100 percent gravel (1/4–3/8 inch), 100 percent sand, or sand mixed with resinous materials (Hydrophyllic Polymer) to decrease the sand density and facilitate the root penetration to reach the nutrient solution. The beds, whether in single or multilayer, can either be stationary or movable to enhance light distribution and optimize growing conditions. Recently a new technique has been developed called the nutrient film technique whereby solid media is used. The nutrient solution is continuously flowing through a tube forming a film approximately 1/9 inch thick. The plants are suspended through openings at the upper side of the tube so that the roots would touch the film solution.

History of Hydroponic Agriculture

Some authorities date the origin of the hydroponic method back to the 16th century when plants were experimentally grown in water to determine the minerals necessary for growth. Dalrymple[1] indicated that the Romans developed cold frames, glazed with transparent stone (perhaps mica, alabaster, or talc), in order to supply Emperor Tiberius Caesar (Reign 14 to 37 A.D.) with a cucumber every day of the year. Mollet and Watts used heated greenhouses in France and England in the 16th century and in Holland in the early 17th century. By the end of the 1800's commercial production of vegetables using greenhouses was well established.

It is believed that in still earlier times the Aztecs in Mexico used a form of hydroponics on rafts at Xochimilco well before Cortez came to the New World. However, on a commercial basis, hydroponic culture is quite new and in combination with controlled environment, newer still.

During World War II, hydroponic agriculture received some attention in the United States. It became operational on the Caroline Islands by early 1945. From this initial effort, many other installations followed in the Pacific Atolls and eventually in Japan where an 80-acre installation supplied fresh vegetables to the American Forces in Korea. Six months after these gardens in Japan were established, it was possible to eliminate the shipping of most salad vegetables across the Pacific.

Advantages of Hydroponics

Just what are the advantages of the hydroculture techniques?

1. The products are superior in appearance, flavor, and overall quality; this is made possible by giving the plant optimum feeding and environmental conditions not normally found in any combination of conventional climate and soil.

2. Crops can be grown the year around (multi-cropping) without dependence on seasonal and weather conditions such as those required by conventional agriculture.

3. The hazards associated with conventional growing such as drought, freezing weather, hail, wind, weeds, and soil diseases, can be eliminated.

4. Pest control is much easier and much more effective under hydroponic conditions.

5. Production is significantly higher than that obtained under conventional agriculture; for example, in a given space it is possible to grow approximately 10 to 50 times as much product (see Table 1).

[1] D.G. Dalrymple, 1973. Controlled environment agriculture: a global review of greenhouse food production — Foreign Agriculture Economic Report No. 89, Economic Research Service, USDA. Available from the Superintendent of Documents, US Government Printing Office, Washington, DC 20402 (Stock No. 00119—00285).

Table 1

Yields in Totally Controlled Hydroponic Techniques
Compared to Conventional Greenhouse and Field Grown Crops

	Pounds/Square Foot/Year			Crops Per Year			Yield Increase Over	
	Hydro-ponic	Green-house	Field	Hydro-ponic	Green-house	Field	Green-house	Field
Lettuce	35	3	1.5	12	4	3	10 times	20 times
Tomatoes	15	5	1.5	3	2	1	3 times	10 times
Cucumbers	50	9	1.0	4	2	1	6 times	50 times

6. Water requirements are dramatically reduced. It takes 30 to 100 times as much water to grow a similar vegetable crop or pasture grass in the field.

7. The hydroponic techniques can be used where soil is poor or nonexistent, such as that in the desert regions.

8. Hydroponic agriculture is ideal for plant breeding purposes due to the total control and prevention of cross breeding; thus, opportunities for the development of new food sources can be significantly enhanced.

9. Hydroponic farms can be located near the consumer, thereby eliminating shipping cost and reducing processing and storage requirements.

Disadvantages

There are, of course, some disadvantages associated with hydroponic agriculture.

1. The original construction cost per acre is great.

2. Introduced soil born disease may be quickly spread to all beds on the same nutrient tank of a closed system.

3. Energy consumption required to control the hydroponic environment such as heat, light, humidity, etc. is high. However, the fact is that in many areas where sunlight is abundant throughout the year, as in many countries in the Middle East, energy requirements can be drastically reduced. This is also true in the United States where commercially grown vegetables by hydroculture have become a reality in many areas, especially in Arizona where the sunlight is available almost the year round. It is, therefore, not surprising that experiments in hydroponic techniques are underway in Abu Dhabi, Puerto Penasco, Mexico and Khark Island, Iran on a cooperative venture with the University of Arizona as well as in Lebanon with the cooperation of Hydroculture, Incorporated of Arizona. Research and development projects devoted to hydroponic techniques are being undertaken in universities, government agencies, as well as

the industry. New knowledge is accumulating rapidly and the technical problems with earlier systems have largely been solved. Research is also being carried out in many European countries, such as Russia, Germany, and others.

Self-contained hydroponic units have now been shown to be cost competitive with conventional agriculture in certain areas of the world and highly practical for certain agricultural applications. This is true even in places where sunlight is rather limited. The fact is that large corporations, such as General Electric, are actively involved in the development of totally controlled Environment Agriculture Units. This is another criterion for estimating the economic feasibility of such systems. A number of U. S. firms are involved in manufacturing hydroponic units such as Environmental Growth Chambers of Chagrin, Ohio and Growth Systems of Glenview, Illinois, and there are a number of others. Special lamps have been designed to produce light approximating natural sunlight. These lamps are available commercially, for example the Gro-Lux and Sun-Brella to name but two of many.

Future of Hydroponic Agriculture

Scientists have indicated that the present world population of 3.9 billion will double within the next 25 years. This is alarming indeed, since hunger and famine have already reached an epidemic level in many areas of the world, due to drought and other uncontrollable natural phenomena. Today, almost all the world's land that is economical to cultivate, some 3.6 billion acres, is under tillage. Only a few are left: namely, the exploration of oceanic food resources and the manufacture of fabricated foods from unconventional sources. The need for high yields of food products within a given area is now and will become an ever increasingly imperative in order to keep up with the rapid expansion of the world population. Hydroponic agriculture is a leading candidate for relieving this problem. It can be effectively applied in the production of selected fruits and vegetables, such as strawberries, tomatoes, cucumber, green beans, okra, eggplants, squash, swiss chard, lettuce, radishes, onion, peppers, cauliflower, cabbage, beets, as well as animal feeds, such as grain and alfalfa. Flowers and ornamental plants which are considered good cash crops can be successfully grown hydroponically. In addition, fish, shrimp, and other foods from the sea can also be grown commercially under controlled conditions.

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